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STUDIES ON THE POTAMIDID SNAIL, *CERITHIDEA (CERITHIDEOPSILLA) CINGULATA* (GMELIN, 1790) (MOLLUSCA : MESOGASTROPODA)

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN MARINE BIOLOGY

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CENTRE OF ADVANCED STUDY IN MARINE BIOLOGY

ANNAMALAI UNIVERSITY

ANNAMALAINAGR

Dedicated to my brother
Thiru P.V. Jeyavelu, M.A.,
F.F.I.I., Sahithya Rathna,
as a token of my affection
and gratitude

DECLARATION

Certified that this thesis is a record of research work done by the candidate, Thiru P.V.Sreenivasan during the period of his study at the Centre of Advanced Study in Marine Biology, Annamalai University and that it has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title.

Parangipettai

4th September 1985

(R. NATARAJAN)
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C O N T E N T S

1. GENERAL INTRODUCTION

1.1 PREAMBLE

Among mesogastropods, Potamididae, which comes under superfamily Cerithiacea, forms an important constituent in the molluscan fauna of estuarine and intertidal region. At Porto Novo, three species of this family belonging to two genera, Cerithidea and Telescopium, are common. The three species are different in their habit and habitats forming their own micro-ecological units and without competing with each other's territory. Their abundance in the estuarine system is really fascinating. Particularly, Cerithidea (Cerithideopsilla) cingulata, is distributed in the Vellar estuary more widely than the other two and reaches an astonishingly very high number of 12000/m^2 and such enormous density is paralleled only by Hydrobia sp. (Hunter, 1964), in the temperate estuaries. On the otherhand, Telescopium telescopium, the shell of which attains a very large size of about 11 cm, occurs in comparatively lesser numbers. Cerithidea (Cerithidea) obtusa, is moderate in size and its density also is moderate, never reaching more than 100/m^2. C. (C.) cingulata prefers submersion and periodical exposure, but C. (C.) obtusa prefers mainly exposure and avoids submersion. On the otherhand, T. telescopium takes

both submersion and exposure equally well. Thus, their accommodation to each other, physiological and anatomical adaptations are matters of fascinating study.

Estuarine ecosystem is a dynamic environment where not only salinity fluctuation is the chief alteration produced by marine and freshwater influxes, but environmental factors such as temperature, incineration, desiccation and wave action also exert stress especially on the intertidal organisms. Survival of the animals in such conditions needs suitable adaptations to cope with extreme conditions and mere survival is different from more subtle physiological adaptations including reproduction. C. (C.) cingulata has successfully coped with such extremities, as evidenced by its enormous biomass. This species has, therefore, been selected for detailed studies on distribution pattern of populations, age and growth, digestive organ and digestion, reproduction and development.

Many molluscs, including the cuttlefish, squids, clams, oysters and mussels, were not given due credit as sea food until recent times and still they are yet to find a place in the Indian culinary. At Porto Novo area, only shells of the clam Meretrix and those of the oyster Crassostrea are used for lime making. There is no

wonder, that, snails like Cerithidea, which are of smaller size, do not attract the attention of the enterprisers. Except in the Tuticorin region, where it is used for making special lime (Hornell, 1951), this snail was never looked upon as a resource of any value. With 20% meat in the shell, with prolific breeding and abundant population, it can serve as a useful source for poultry feed where the calcified shell bits will be of immense use. An attempt in this direction may lead to find some utilisation for this unutilised resource.

1.2 REVIEW OF PREVIOUS WORK

Literature on potamidids is scattered and scanty. Majority of the works are taxonomic in nature, listing the species with very little description.

According to Thiele (1931), the family Potamididae includes seven genera under the subfamily Potamidinae, and two genera under the subfamily Batillarinae; according to Taylor and Sohl (1962), this family includes 37 genera and subgenera. Of this, only three genera represented by three species, namely Cerithidea (Cerithideopsilla) cingulata

(Gmelin, 1791), Telescopium telescopium (Linnaeus, 1758) and Batillaria anguilifera (Sowerby, 1866) were reported to occur in India by Rajagopal and Mookherjee (1982). At Porto Novo, in addition to C. (C.) cingulata and T. telescopium, another species, Cerithidea (Cerithidea) obtusa (Lamarck, 1822), also was recorded during the period of this study. Rajagopal and Mookherjee (1982) reviewed the various synonyms of these potamidids. Nishikawa (1962) has recorded the chromosome number of C. (C.) cingulata as n = 16.

Ecological observations on potamidids have been made by Vohra (1970) on C. (C.) cingulata from Singapore beach, and by Wells (1980) on Terebralia sulcata and T. palustris, in the mangrove swamps of north western Australia. Vermeij (1973) studied in detail the physiognomy, diversity and regional differences among molluscs in mangrove swamps including the potamidids, C. obtusa, C. quadrata, C. (C.) cingulata, T. telescopium and T. sulcata. Race (1979, '82) dealt with interference and competition between the native C. californica and the introduced snail Ilyanassa obsoleta, in San Fransisco Bay. In another study, she described the ecology and natural history of the population of C. californica, from the same area (Race, 1981). Balaparameswara Rao and Sukumar (1982) have given an account on the distribution of C. (C.) cingulata, in the Nizampatnam canal (Southeast India).

Ecophysiological studies on potamidids are those of Scott and Cass (1977) on the effects of lowered salinities on C. californica and of Balaparameswara Rao and Sukumar (1981) on the response of C. (C.) cingulata to different types of substrata. Effects of desiccation, temperature and salinity on C. californica were also observed by Race (1981).

Tidal activity rhythm in the snail, C. decollata, was observed by Cockcroft and Forbes (1981b). Effect of Copper Sandoz on C. (C.) cingulata, was studied by Mintardjo and Sunaryanto (1979) while the Aryl sulfatase activity in C. (C.) obtusa was observed by Dhevendran et al. (1980).

Prabhakara Rao (1980), Prabhakara Rao and Prasada Rao (1983), have described the effects of salinity, effects of body size, and temperature on respiration, end product of anaerobic metabolism and aerial respiration in C. (C.) cingulata.

Parasitic infestation by the larval digene on C. californica, was reported by Yoshino (1975) and an annotated key to the cercaria occurring in the same species has been given by Martin (1972).

Berry (1963) traced the distribution pattern of C. quadrata, C. (C.) obtusa, T. sulcata, T. micropterus and T. telescopium, while, Brown (1971) gave an account of

distribution and movement of C. decollata, in the South African Mangrove swamps. Distribution of C. decollata in the mangrove swamps of the same area, was also observed by Kalk (1959), Macnae and Kalk (1962) and Macnae (1963). Occurrence of T. palustris in the Durban Bay estuaries was recorded by Day and Morgans (1956) and Pyrazus ebininus by Vohra (1965) in Singapore mangroves.

Growth studies on potamidids included those of Sewell (1924) and Rao (1938) on P. palustris, Sadasivan (1947), Ramamoorthi and Alagaraja (1969) and Vohra (1970) on C. (C.) cingulata, Race (1981,'82) on C. californica and Cockcroft and Forbes (1981a) on C. decollata.

Morphology of the radula in P. palustris was reported by Annandale (1924). Anatomy of digestive system of potamidids is available in the works of Seshaiya (1932), Sadasivan (1947) and Swaminathan (1961) from India. Bright (1958) and Driscoll (1971) described the functional morphology of C. californica, while the latter author enumerated that of Batillaria zonalis also. Food of C. costata was given by Garrett (1970), while the food and feeding habits of B. atramentosa and C. californica were studied by Whitlach and Obrebski (1980). Alexander and Rae (1974) described the structure and formation of crystalline style in

T. telescopium, while Alexander et al. (1979) dealt with the composition and enzyme content of the crystalline style in the same species. Cutler and Yellowlees (1979) and Yellowlees (1980) studied the enzymes of the crystalline style also of T. telescopium. Swaminathan (1961) made observations on the digestive enzymes and their activity in T. telescopium.

Johansson (1956) described the anatomy of Tympanotonus including reproductive organs. Reproductive system of T. telescopium was dealt by Swaminathan (1961) and its spawning by Ramamoorthi and Natarajan (1973). The spawning habit of C. (C.) cingulata was described by Panikkar and Aiyer (1939). Spawn and egg mass of the same species figured in the work of Natarajan (1958). Habe (1955) described spawning in C. djedjariensis and C. rhizopharum. Bright (1960) described the reproductive system of both male and female of C. californica. Houbrick (1984) in an exhaustive account reviewed the literature on the genus Cerithidea.

1.3 SCOPE OF THE PRESENT STUDY

Taking into consideration the lacunae in our knowledge on the potamidid C. (C.) cingulata, which occurs most abundantly in Porto Novo area, the present work has been

designed as a detailed study on the ecology, growth, digestion and reproduction of C. (C.) cingulata.

Potamidids (three species) of Porto Novo area were studied for general organisation so as to bring out salient features. Morphology of shell as well as that of visceral organs were studied. Differences in the protein pattern of myogen were also studied by electrophoresis.

Detailed investigations have been carried out on the distribution, physiology and biological aspects of C. (C.) cingulata.

Physico-chemical and biological characteristics of the environment influence the distribution, as well as other biological activities of the snail. Therefore, environmental parameters, such as rainfall, salinity, temperature, dissolved oxygen, pH, organic carbon content of the sediment, texture of the sediment, phyto- and zooplankton abundance in the water mass, macrovegetation and the fauna associated with the snail were also studied.

Tolerance to adverse conditions is essential for survival and continuation of a population in any environment. Being an estuarine intertidal snail, C. (C.) cingulata is normally exposed to extremes in salinity, temperature and atmospheric exposure. Optimal, tolerable and lethal limits

of these characteristics for the snail were thus investigated.

Differential distribution and abundance over space and time, length composition, tidal rhythm and dispersal are characteristics of the population. These aspects have been studied in detail in C. (C.) cingulata.

Growth is an important aspect of any biological study and for C. (C.) cingulata, it was estimated by both direct and indirect methods. Age composition of the population was also enumerated.

The digestive system and qualitative and quantitative studies on the enzyme activity of different regions of the gut alongwith its microflora, are necessary to know about the capacity of the snail to utilise the spectra of food available in the environment. Therefore, investigations were carried out on these lines also.

Knowledge on reproductive organs, reproductive cycle, size at first maturity, sex ratio, mating, spawning, larval development and spat settlement, is most essential to understand the survival and flourishing of successive generations. Detailed observations have been made on the reproductive biology of C. (C.) cingulata.

1.4 DESCRIPTION OF THE STUDY AREA

The Vellar estuary, a positive bar-built estuary, is located in the South Arcot District of Tamil Nadu in the Southeast coast of India (lat. 11°29' N; long. 79°46' E) (Fig. 1). The river Vellar originates at Servaroyan Hills of Salem District and after running a course of 480 km, joins the Bay of Bengal at Porto Novo. The Vellar estuarine system is being augumented by the confluence of a channel from the Coleroon estuary (lat. 11°28' N; long. 79°49' E) running parallel to the sea. By the side of this confluence, lie various creeks and mangrove swamps called Pichavaram mangroves, covering an area of 1100 hectares. The Coleroon estuary, a distributory of the river Cauveri, is three times wider than the Vellar estuary and receives copious fresh-water supply by drainage during monsoon season and by the excess water let off for agricultural purposes.

In between the Vellar and Coleroon estuaries, an irrigation channel - the Khan Sahib canal, joins the system midway and opens into the sea through a mouth near Chinnavaykal. Thus, the estuarine complex receives neritic water supply from the Vellar mouth, the Chinnavaykal mouth and the Coleroon mouth.

The river mouth of Vellar is not a stable one,

shifting from year to year, depending mainly on the quantum of river inflow during monsoon and also to certain extent by the sand bar built by tidal influence. During 1982-'83 (upto monsoon season of the latter year), the bar was lying north of the fish-landing centre, opposite to the Light House and the river was confluent with the sea only by a narrow channel. But during the monsoon months of 1983, due to heavy floods, the bar was eroded and the mouth shifted to a straight course. A similar feature was observed by Sivakumar (1982) during 1977.

The Vellar estuary is subjected to semidiurnal tides with a maximum tidal amplitude of about 1 m. Higher tidal range is observed during north-east monsoon period (October-December) and a lower range during the summer (April-June). Influence of the tide can be felt to a distance of 10-12 km upstream from the river mouth.

The average depth of the estuary is 2.5 m with a maximum of 5.3 m on the opposite side of the Biological station. Generally, the southern part of the river is deeper upto 8 km upstream after which the northern part is deeper. The estuary is 600 m wide at the junction of the sea but narrows down considerably in the upper reaches near B. Mutloor (8 kms upstream).

Hydrographic changes in the Vellar estuary are brought about by the influence of freshes and neritic water ingression from sea. The estuary is subjected to diurnal and long term salinity changes by these influences. Many physico-chemical properties are altered by oscillating semi-diurnal tides as well by the freshwater supply from the Veeranam lake and Manimutha reservoir (feeder systems).

Porto Novo area as also the entire Tamil Nadu coast are influenced by the north-east monsoon (October-December). Precipitation during the southwest monsoon (July-September) is scanty with 300 mm spread over 4 months in a normal year. The bulk of the rainfall is during the northeast monsoon period ranging between 1200 and 1300 mm. This heavy precipitation influences both the physiography and the hydrography, as also the faunal and floral composition profoundly. The postmonsoon (January-March) is the recovery period (after the monsoonal floods), summer (April-June) is a stable period hydrographically with neritic water domination, while premonsoon (July-September) is a transition period, whereas, the monsoon (October-December) is characterised by heavy downpour with heavy freshwater flow (floods) in the river.

Based on salinity characteristics, the Vellar

estuary is divided into 4 zones by Ramamoorthi (1954) following the classification of Rochford (1951). (1)The marine zone, extending from river mouth to 1.5 km upstream, is stable in salinity conditions and does not have surface-bottom salinity variations; (2)the gradient zone lies next to the marine zone upto a distance of about 2 km above and is characterised by a vertical salinity gradient; (3)the tidal zone, which covers another 2 km upstream from gradient zone is characterised by a progressive decrease in salinity; and (4)the freshwater zone in the upper reaches where the salinity gradient totally disappears. This classification is only tenurial and is always subjected to alterations, depending on tidal influence and freshwater flow.

Besides the aquatic microflora, macro-algal components include mats of Enteromorpha, Chaetomorpha, Padina, Ulva, and Gracilaria dominating in the marine zone. Angiosperms like Cymodacea and Halophila occur in the intertidal regions of the estuarine complex. In the adjoining mangroves, 53 species of plants have so far been identified, of which Rhizophora, Avicennia, Sonneratia, Aegiceros, Bruguiera, Ceriops, Acanthus, Exocaeria and Suaeda are most common.

Faunal composition of the estuary is highly varied, including many phyletic constituents. Foraminiferans,

turbellarians, nemertinean worms and nematodes are the main components of meiofauna. Among macrofauna, polychaetes like Pisione, Lumbriconereis and Pseudopolydore, among crabs Uca, Dotilla, Macrophthalmus and Clibanarius and among molluscs Meretrix, Katelysia, Sanguinolaria, Tellina, Solen, Clithon, Cerithium, Cerithidea, Telescopium, Natica, Nassa, Umbonium, Crassostrea, Saccostrea and Anadara are most common. Mangrove macrofauna includes the molluscs Cerithidea, Telescopium, Nerita, Cassidula, Pythia and Melampus and crabs like Scylla and Grapsis.

In this part of the Vellar-Coleroon estuarine complex, three sites were selected for regular monthly sampling in order to know the variables associated with the population density changes and growth of C. (C.) cingulata. Sampling was carried out for a period of 24 months from September 1982 to August 1984.

Site 1 (River Mouth)(Fig. 2):

This is located in the marine zone close to the sea. Neritic water dominates in this site, as reflected well by hydrography. Wave action, though not strong, as in the open beach, is still felt during high tide, particularly in 1983-'84. Vast area of the intertidal region is exposed during extreme low tides around newmoon and

fullmoon. Depth ranges from 1 to 1.5 m. Due to its nearness to the fish landing centre, the area is polluted by spoiled fish and fish refuse. However, due to tidal influence, the water and the substratum are clear of H_2S.

Site 2 (Buckingham Channel)(Fig. 3):

This is located 3 km upstream from the mouth in a tidal creek. Water movement is observed only as tidal flow or as occasional floods. In its sheltered location, the substratum of this area is muddy. The width of the canal is 30 m. Adjoining the canal are salt pans from which brine seeps out. However, no extreme changes in salinity were noted, due to good tidal flow. Often, extreme low tides expose the whole area leaving behind only a narrow water passage.

Site 3 (Killai Backwaters)(Fig. 4):

This site is located 7 km south of the mouth of Vellar and 6 km north of Coleroon mouth. The intertidal area is wide. The estuarine part of the area is the site of the Pichavaram mangroves. Due to the adjoining freshwater source, the Khan Sahib canal, the area is less saline than the other two sites.

The above three areas were selected so as to

cover one open area, another in the side creek and the third located in the backwater area. This also covers the marine zone, the gradient zone and the tidal zone.

Fig. 1. Map of Vellar estuary. (Location of Porto Novo indicated in the map of Peninsular India)

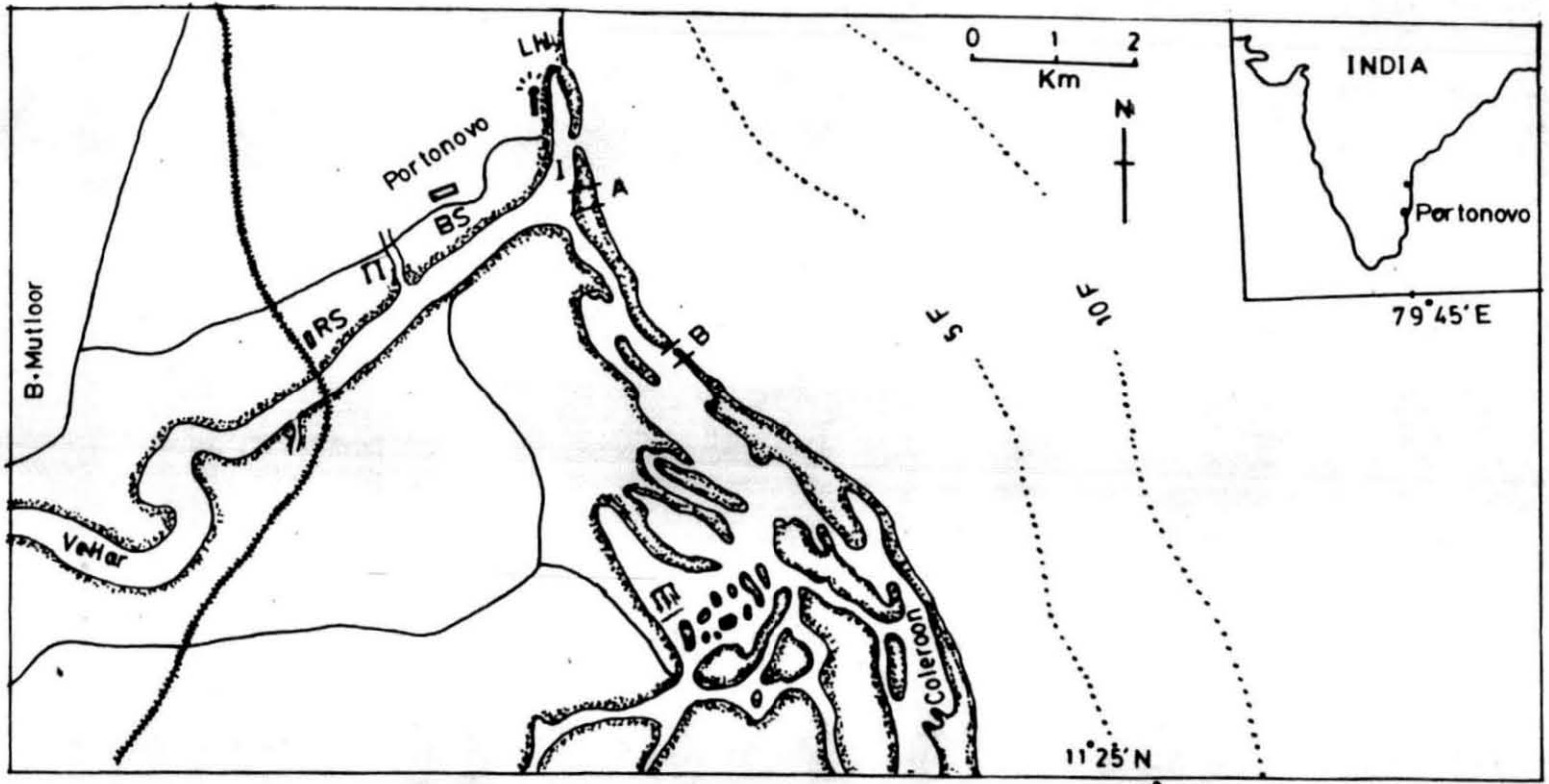
A : Mouth of Vellar in 1983-'84

B : Mouth of Chinnavaykal

BS : C.A.S. in Marine Biology

LH : Light House

RS : Railway Station


LH
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10F
11°25'N
79°50'E

FIG 1

Fig. 2. View of sampling Site I (Mouth of Vellar)

Fig. 3. View of sampling Site II (Buckingham Channel) (Vellar estuary in the background)

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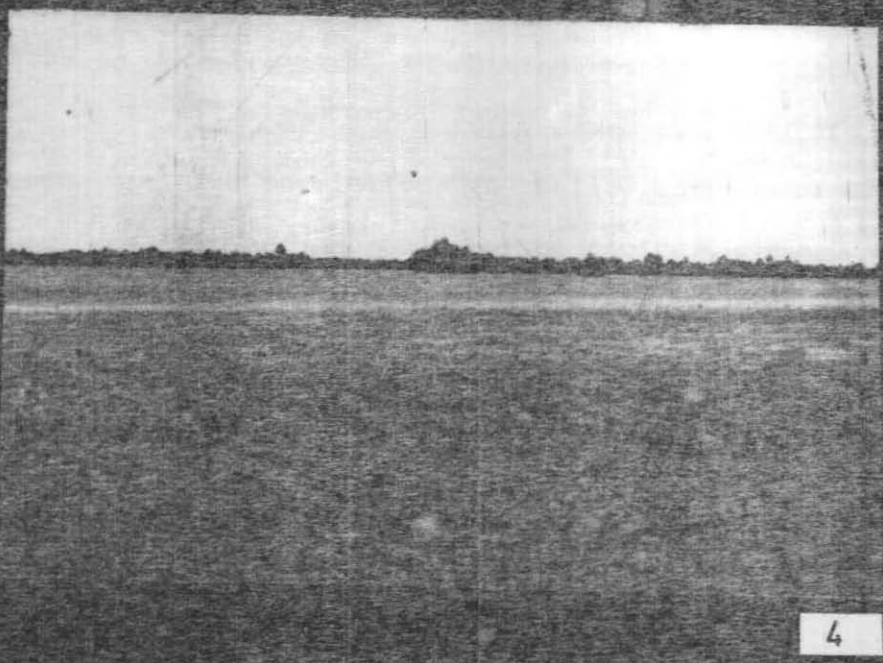
Fig. 4. View of sampling Site III (Killai Backwaters)
(Islets with mangrove plants in the background)



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2. POTAMIDIDS OF PORTO NOVO

2.1 INTRODUCTION

Members of the family Potamididae include snails of smaller to moderate size, inhabiting mainly the brackish-water estuaries, lagoons, and mangrove swamps. They are often found as large populations in shallow intertidal areas throughout the tropical and subtropical regions.

The potamidids have been divided into two subfamilies, Potamidinae and Batillarinae by Thiele (1931). The former subfamily includes 7 genera, namely, Pirenella Gray, 1847, Royella Iredale, 1912, Tympanotonus (Klein) Schumacher, 1817, Cerithidea Swainson, 1840, Telescopium Montfort, 1810, Pyrazus Montfort, 1810 and Terebralia Swainson, 1840. The subfamily Batillarinae includes two genera Batillaria Benson, 1842 and Rhinocoryne Martens, 1900. Taylor and Sohl (1962) recorded 37 genera and subgenera under the single family Potamididae.

From India, four genera and 5 species are authentically known (Gravely, 1927; Seshaiya, 1932; Crichton, 1940; Hornell, 1951; Satyamurti, 1952; Rajagopal and Mookherjee, 1982). They are: Cerithidea (Cerithideopsilla) cingulata (Gmelin, 1790), Cerithidea (Cerithidea) obtusa (Lamarck, 1822), Telescopium telescopium (Linnaeus, 1758), Terebralia

palustris (Linnaeus, 1758) and Batillaria anquilifera (Sowerby, 1866).

In the Porto Novo area, the family Potamididae is represented by three species belonging to two genera viz., C. (C.) cingulata, C. (C.) obtusa and T. telescopium under the subfamily Potamidinae. So far no detailed study has been carried out on these snails from this area, but only some scattered observations having been made (Seshaiya, 1932; Swaminathan, 1961; Ramamoorthi and Alagaraja, 1969; Ramamoorthi and Natarajan, 1973).

2.2 MATERIAL AND METHODS

Specimens of C. (C.) cingulata were collected from the Vellar estuary and Killai backwaters, those of C. (C.) obtusa from the mangrove of Pichavaram and the specimens of T. telescopium from all the above areas.

The snails were brought to the laboratory, cleaned and examined for shell characteristics. Anatomical drawings were made in fresh condition using an Olympus Trinocular Microscope and a mirror-type camera lucida at table top magnification.

The radula was dissected out, kept in 5% KOH for 12 hours to digest the tissues, then transferred to 10% acetic acid and kept for another 12 hours, before it was washed with distilled water and graded through alcohol and mounted in DPX mountant, without any staining. The figures were drawn under 15 x 40 and 15 x 20 magnifications.

The terminology used were those employed by Van Benthem Jutting (1956) and Houbrick (1978).

For polyacrylamide gel electrophoresis, Davis and Lindsay's (1967a) method was followed. In all cases the snails of normal health and vigour only were used. Foot muscle was collected only from mature female snails. Gonads were obtained from mature specimens. Fresh snails were used to remove the tissues required.

Thirty mg of tissue/ml was taken for all analyses. The tissues were homogenised in glass tufflon microtest tube homogeniser. The homogenised tissue was centrifuged for 15 minutes at 3000 rpm and the supernatent solution containing the water soluble proteins was used for electrophoretic separation.

The three layered polyacrylamide gel disc electrophoresis (Ornstein, 1964; Davis, 1964; Davis and Lindsay, 1967a, b; Smith, 1976) was used in the present investigation.

The chemical formulations described by Canalco Bulletin, 1968 (1968) was used for the preparation of various stock solutions and the combination of these stocks, in actual processing of electrophoresis. The separating gel was the standard 7.5% polyacrylamide gel. 1 ml of the tissue extract was mixed with equal quantity of sampling gel and 0.2 ml of the above mixture was placed on the spacer gel in each tube.

Circular electrophoretic separating chamber with 12 tubes was used for the study. A steady current of 5 mA/ tube was applied for protein separation. The power supply was cut off when the Bromophenol Blue dye mark travelled 40 mm from the origin of the separating gel. The gels were immediately recovered from the glass tubes for staining purposes. Extracts of foot tissues from three species were electrophorased simultaneously and so also the gonadal tissues. The runs were made 5 times using extracts from different snails, so as to obtain comparable results.

Staining techniques

Two types of stains were used.

(1) Coumassie Brilliant Blue (for total/general proteins): 0.2% stain dissolved in methanol:acetic acid:water (5:5:1), was used after fixing the gels in 10% Trichloroacetic acid.

The gels were destained in 7% acetic acid and preserved in the same.

2. PAS reaction (Glycoprotein): Staining was carried out according to the procedure given in Eastman Data Service No.JJ 11. The gels were kept in 1% periodic acid in 3% acetic acid for one hour, washed in running water for one hour and stained with Schiff's reagent for 1 hour. The gels were destained in 5% sodium metabisulphite and preserved in the same solution. Preservation in the solution for longer duration allowed the stain to fade, but on keeping in running water, the gels regain the colour density.

Mobility of individual fraction from origin was measured and the relative mobility (Rm) was calculated taking the distance from origin to the front as 1.0 unit. The Rm is expressed to the nearest 0.005 units. For convenience, the protein fractions were grouped under three catagories based upon their relative mobility values: (1) slow moving (upto 0.33), (2) intermediate (0.34 to 0.66) and (3) fast moving (0.67 to 1.00). The Rm values were calculated for each gel and the average for 20 runs were used for final results.

2.3 GENERAL CHARACTERS

Accounts on morphology and functional anatomy of the potamidids are limited and scattered. The important works are those of Annandale (1924) on Pyrazus palustris of Seshaiya (1932) on C. (C.) cingulata, C. (C.) obtusa and T. telescopium, of Sadasivan (1947) on C. (C.) cingulata, of Johansson (1956) on Tympanotonus of Bright (1958, '60) on C. californica, of Swaminathan (1961) on T. telescopium, of Driscoll (1971) on C. californica and B. zonalis and of Alexander and Rae (1974) on T. telescopium.

In the present study, a brief description of the general characters of the potamidids based on three species are given.

2.3.1 Shell

Shells of potamidids are characteristically elongate, turrated and fairly thick. The aperture is ovate with a short anterior siphonal canal. The outer lip is flared and grows beyond the columellar base. The outer lip is thickened in older specimens. The shell is stronglly sculptured in both Cerithidea and Telescopium. In the former, both the axial and spiral sculptures are evident,

while in the latter only spiral ridges are present. Periostracum is colourless. In T. telescopium, the shell is dark in young specimens but greyish in older ones. Shells of C. (C.) cingulata are uniformly dark coloured or mottled with brownish yellow spots, particularly on the lower row of nodules in each whorl of the shell.
C. (C.) obtusa is pale pinkish without any mottling. Protoconchs are small and normally lacking in older specimens especially in C. (C.) obtusa. Operculum is ovate with a central nucleus and concentric lines of growth. It is generally thin, chitinous and brown or dark.

2.3.2 External features (Figs. 5 & 6)

The visceral organs in general are greyish but individual organs show different colouration. Foot is dark in C. (C.) cingulata and T. telescopium while it is red in C. (C.) obtusa. The head is dark in the former two species while in the latter, it is red and black banded alternately. The stomach region is bluish-green while the gonads appear creamy (mature female) or bright yellow (mature male). Columellar muscle is invariably white. The region near the kidney is iridiscent.

The foot is massive, highly contractile and

capable of considerable expansion during locomotion. The propodium, invested with mucus secreting cells, has a network of connective tissue and muscle fibres. The chitinous operculum is attached to the metapodium. The foot is innervated from the paired pedal ganglia situated at the juncture of head-foot region.

The head is broad with a prominent snout which is wrinkled and highly contractile. The mouth is crescentic and situated at the anterior tip of the snout. The tentacles project from the neck, are stumpy at the base but from the position of eye, somewhat thinner. The tentacles are spotted with black in C. (C.) cinculata and T. telescopium, but are banded in C. (C.) obtusa with red and black.

.... Mantle cavity and associated organs (Figs.7.A,B & 8)

The organs of the pallial complex are the osphradium, ctenidium, hypobranchial gland, intestine, rectum and the genital tracts. The surrounding mantle is thick and muscular at its free edge. The dorsal and lateral edges of the mantle are smooth and without crenulation. In the inhalent siphon area, the mantle edge is modified into muscular fold, but not so distinctly in the exhalent siphon area. There is a very narrow groove leading from the

exhalent siphon area to the foot in the females. The mantle cavity is very deep.

The osphradium is elongate and prominent extending from kidney-heart region anteriorly to the inhalent siphon. It is bifurcated and each part is triangular in shape. A thick nerve runs beneath the osphradium.

The well developed ctenidium is large and occupies a considerable portion of the mantle cavity, but it narrows down posteriorly. The ctenidium is separated from the osphradium by a narrow space. It is highly vascularised at the posterior region as an adaptation to partial aerial breathing.

In C. (C.) cingulata, the hypobranchial gland covers the entire region from the exhalent canal to the ctenidium anteriorly. It is traversed and bifurcated by the rectum anteriorly and restricted and located between the ctenidium and the intestine posteriorly. The hypobranchial gland secretes copious mucus to bind the extruded faecal matter from the rectum so as to keep them away from the ctenidium to avoid contamination.

The intestinal and rectal portions of the alimentary tract lie in the visceral complex between the hypobranchial gland and the gonoduct. The anus is located

slightly behind the mantle edge, near the exhalent siphon.

The genital ducts appear as folds and grooves and are coloured pale yellowish. They extend almost the full length of the mantle cavity from the anterior to the posterior end.

2.3.4 Alimentary system (Fig.9)

The digestive system of the potamidids has been described by Seshaiya (1932), Sadasivan (1947), Bright (1958), Swaminathan (1961), Driscoll (1971) and Alexander and Rae (1974).

The terminal crescentic mouth opens into the buccal cavity. At the anterior end, the buccal cavity lodges a pair of triangular chitinous jaws embedded in the dorsal wall of the cavity. The buccal mass or odontophores is muscular, red in colour and anchored dorsally to the body wall by strong muscles. The radula (Figs.10-12) is typically taenioglossate viz., one median, one lateral and two marginals (2-1-1-1-2) (Fig.13.A&B). The median tooth, smaller than the other, has a upper broader edge which bears a middle cusp and three lateral cusps on each side. The ventral triangular portion is smooth near the base.

The lateral tooth bears about 5 to 6 cusps. The marginals are narrow and elongate and appear hook-like and bear strongly curved cusps. The number of rows of teeth varied from 65 to 71 in C. (C.) cingulata, 142 to 160 in C. (C.) obtusa and from 80 to 87 in T. telescopium. At its rear end, the radula confluences with radular sac which secretes the radula. This region is provided with strong musculature for the movement of radula.

The salivary glands are thin and elongated. The dorsal food channel of the anterior oesophagus shows a characteristic twist at the region of torsion, posterior to the nerve ring and comes to lie ventrally in the posterior oesophagus.

The stomach is quite large, with many muscular folds and ridges. Oesophagus opens into the stomach midventrally. Digestive gland opens by a pair of openings closer to that of the oesophagus. Style sac is well developed and secrets the proteinecious crystalline style, which dissolves to release the digestive enzymes. The hindgut includes the intestine and the dilated rectum, which opens into the mantle cavity by the anus. The digestive gland is an elaborate structure lying posteriorly to the stomach extending up to the apical whorls.

The entire alimentary tract is provided with thick cilia for transportation of food particles. Extensive mucus secreting cells are found in the foregut for binding the food particles and in the hind gut for binding the faecal matter.

Food of potamidids consist generally of fine organic, particulate detrital matter settled on the substratum. The snails scrape off the food matter with the help of the radula, and swallow along with it, a lot of sand particles. Benthic as well as the settled diatoms on the bottom are also found in the stomach contents. Algal bits are also quite common.

2.3.5 Reproductive system

Potamidids are **dioecious** and aphallic, rendering external sexual determination difficult. However, in adults, the colour of the gonads varies with sex - creamy colour in female and yellow in male. The female of C. (C.) cingulata possesses modified metapodium which is swollen and bright yellow and can be easily recognised.

Gonads are closely associated with the digestive gland making it difficult to separate them from each other.

The testis is follicular in nature and each follicle leads into a tiny tubule, which in turn leads into a vas deferens, running along the collumellar side of the visceral coil. The vas deferens enters the open pallial gonoduct near the stomach (Fig. 14.A). The pallial gonoduct possesses two laminae - lateral and median - which are fused dorsally to each other and to the mantle. The ventral margins are free and open into the mantle cavity. The proximal portion of the genital groove is glandular and acts as prostate. The epithelial lining of the inner walls of the laminae, thrown into folds, appears smooth.

Sperms are of two types, eupyrene and apyrene (Figs.14.C & D) as found in cerithiaceans. A spermatophore (Fig. 14.E) is formed to aid sperm transfer from the male to the female. Wall of the spermatophore is produced by the pallial gonoduct (Fretter, 1984).

The ovaries are follicular and superficially interspersed over the digestive gland. The oviduct runs along the columella similar to that of vas deferens. The open pallial oviduct is similar to that of male in general appearance (Fig. 14.B).

The median lamina is non-glandular upto anterior-middle region and glandular from thereon. The posterior

portion of this glandular region secretes the albumen and the anterior, the capsule of the egg. Anteriorly, a long slit, the sperm collecting gutter is present and leads into a ciliated tube-like channel, which runs posteriorly to the sperm collecting pouch. The latter has a fine opening into the lumen near the opening of the closed oviduct. This area is the site of fertilization from which the egg moves anteriorly, via albuminous and capsular regions, by ciliary currents. The eggs leave the mantle cavity and reach the exterior, along the groove in the neck, to the pedal groove formed by the foot.

Egg laying has already been observed in the case of C. (C.) cingulata, by Panikkar and Aiyer (1939) and Natarajan (1958) and in T. telescopium, by Ramamoorthi and Natarajan (1973).

2.3.6 Other systems

The excretory organ in the potamidids is the kidney which is large, flat and spongy, appearing grey to brown in colour. It is located at the left side of the visceral hump. The elliptical slit-like renal opening is situated on the ventrolateral part of the ascending portion

of the kidney, close to the intestine. The opening is sorrounded by cilia.

The vascular system of the potamidids is similar to that of the related cerithiids (Houbrick, 1974b, '78) and other mesogastropods. A two chambered heart is located in a pericardial cavity. The anterior aorta runs forward under the floor of the pericardial cavity, dorsally to the left of the posterior region of the oesophagus and ends in a series of sinuses in the head-foot region. The posterior aorta buds off from the anterior aorta and runs along outside of visceral mass and ends in visceral sinuses. The blood vessels and sinuses are open and poorly defined.

The nervous system of the potamidids is similar to that of Littorina described by Fretter and Graham (1962). The ganglia of nerve ring, the dorsally located cerebral and pleural, and the ventrally located pedal ganglia, are all distinct. Commissures connecting the right and left ganglia to pedal ganglia are thin. Fine nerves branch off from the ganglia and run to various regions. There is a tiny ganglion in the inhalent siphon region in the mantle edge.

The chief sensory organs of the potamidids are the eyes, osphradium and the statocyst.

As already indicated, in the Porto Novo area, three species belonging to two genera, namely C. (C.) cingulata, C. (C.) obtusa and T. telescopium are present. A brief description of them are presented below for the sake of completeness of information.

2.3.7 Cerithidea (Cerithideopsilla) cingulata (Gmelin, 1790) (Fig. 15.A, B & C)

Murex cingulatus Gmelin, 1790. Syst. Nat. Ed., XIII, 1(6): 3561 pp. Sp.138.

Cerithidea cingulata Adam and Leloup, 1938. Mem. Mus. Roy. Hist. Nat. Belg. (Hors. Serie), Vol.2, Fasc.19: 98. Van Bentham Jutting, 1956. Treubia, 23(2): 429-431, Figs.98, 99 and 102.

Cerithidea (Cerithideopsilla) cingulata Rajagopal and Mookherjee, 1982. Rec. Zool. Surv. India, Occ. Paper, 28: 27-29.

Description

Shell high, conical, reaching 39.4 mm in length; whorls 13-15 separated by moderate sutures; prominent spiral ridges in each whorl crossed by axial ribs of about the same thickness, thus forming rows of regular granular nodules; the axial ribs fade away at the upper half of the body whorl; spiral ridges prominent in the body whorl; groove between the first and second spiral rows deeper than those

between the other two rows.

A strong varix or hump present opposite to the aperture in the body whorl in the adult; aperture, oval with narrow ends; columella straight, confluencing with the inner lip at base; outer lip thick and expanded and flared over the siphonal canal; the latter short, but distinct; operculum spherical with central nucleus.

Colouration of the shell differs; some uniformly dark; in others, the lower row of nodules in each whorl yellowish brown while the upper two rows dark brown.

Reproduction oviparous; egg mass in a form of filamentous threads. Egg capsule contains a single egg; development with planktotrophic veliger stage.

Distribution

Persian Gulf, India, Sri Lanka, Burma, Singapore, Malay Archipelago, Southern China, Japan, Philippines and New Guinea.

Fossil record

From the deposits of meiocene and younger age in India, China and Malaya including Java (Van Regteren Altena, 1941).

2.3.8 Cerithidea (Cerithidea) obtusa (Lamarck, 1822) (Fig. 16.A, B & C)

Cerithium obtusum Lamarck, 1822. Hist. Nat. Anim., S.vert.7: 71.

Cerithidea obtusa Verwey, 1930. Treubia, 12: 175, 180, 184
Van Bentham Jutting, 1956. Treubia, 23(2): 433-435. Fig.106.

Description

Shell conical; stout, thin and sculptured; whorls 7 to 8, the apical whorls eroded; tip blunt, maximum length (with decollated tip) 56 mm; about 6 to 7 spiral ridges and about 9 to 10 axial ribs in each whorl; axial sculpture dominates over spirals except at the lower half of the body whorl.

In adult specimens, a weak varix (hump) present in the body whorl; aperture strongly spherical and wide; a short siphonal canal present; flare of outer lip over the siphonal canal not so prominent; columella weak, basal end twisted; operculum circular with central nucleus and concentric growth lines.

Shell usually pale pinkish; foot red; head and tentalce with broad black and red bands alternating; operculum dark brown.

Reproductive strategies not known. Mating observed on one occasion when both male and female specimens

were found on a branch of Rhizophora in Pichavaram mangroves. Spermatophore of moderate size measuring 1 cm in length.

Distribution

India, Malaysia, Siam, Indo-China (Malay Archipelago).

Fossil record

Recorded in the Pliocene layers in Central and East Java (Van Regteren Altena, 1941).

Remarks

Van Bentham Jutting (1956) referred this species as Cerithidea obtusa, without considering the subgeneric status. The shape of the aperture and the radula agree well with descriptions given by Thiele (1931) for the subgenus Cerithidea, under the genus Cerithidea Swainson. Therefore, this species was assigned to this subgenus and referred as Cerithidea (Cerithidea) obtusa (Houbrick, 1984)

2.3.9 Telescopium telescopium (Linnaeus, 1758) (Fig. 17.A, B & C)

Trochus telescopium Linnaeus, 1758. Syst. Nat. Ed. X: 760, Sp.521.

Telescopium telescopium Martin, 1899. Samml. Geol. Reichsmus, Leiden (N.S.) 1: 220. pl.33, Fig.509, 509a.
Van Bentham Jutting, 1956. Treubia, 32(2): 439-441. Fig.100 and 108.
Rajagopal and Mookherjee, 1982. Rec. Zool. Surv. India, Occ. Paper, 28: 30-31.

Description

Shell strongly conical reaching about 11 cm; whorls 13-15 in fully grown specimens; suture in spire are distinctly marked out only in four to five whorls from the anterior end and obscure in others; spiral ridges prominent; apical whorls most often entire with little erosion; varix in the body whorl not evident.

Aperture round, outer lip thickened and folded in older specimens; flare over siphonal canal distinct; siphonal canal not prominent; columella solid with a thick spiral fold which wounds along the entire length, operculum spherical with central nucleus.

Colour dark except along the sutures which are lighter; older specimens grayish.

Oviparous; egg mass filamentous; each capsule enclosing a single egg; development involving planktotrophic veliger stage.

Distribution

Madagascar, India, Sri Lanka, Burma, Malay Peninsula, Singapore, Indonesia, Philippines, and coast of North Australia.

Fossil record

Recorded in the deposits of Meiocene and younger layers in West, Central and East Japan (Van Regteren Altena, 1941).

2.4 HABIT AND HABITATS

C. (C.) cingulata occupies the intertidal area of the Vellar estuary mainly between MTL to LTL. Creeks as well as open shore are occupied by this species. The snail prefers sand mixed with clay substratum. Most dense populations are found near river mouth, dwindling gradually towards the upper reaches. The snail moves with receding as well as with ascending tides. The snail feeds on the detrital matter in the substratum. C. (C.) cingulata is a common inhabitant in the mats of the alga Enteromorpha. The snail is totally absent inside the mangrove proper.

C. (C.) obtusa is found only within the mangrove forest and endemic to that area. The snail climbs the Rhizophora tree upto one metre height and often found in the branches attached by thin dried mucus filament. The snail is found only in the trees near the fringe of mangrove islets. It prefers shady areas indicating its adaptation to humid cool atmosphere rather than to open dry air. It traverses only a few metres away from the water edge towards the land. The snail descends towards the ground during low tides for feeding and ascends during high tide. In the laboratory, the snail is always found above the water mark and avoids submersion. Aerial respiration appears to be dominant over aquatic respiration in this species. The snail subsists on detritus of decomposing leaves, rich in organic matter.

T. telescopium is found in the gradient and tidal zone of the Vellar estuary as well as in and out of the mangrove forest. The snail is never found in large aggregations like the former two species; the density of its population in any area never exceeding 20 to 30 snails/m^2. The snail is always found on the ground and never climbs the trees, though it inhabits the mangrove. T. telescopium is found mainly between HTL and MTL and seldom below that

level. The snail takes submersion and exposure with ease, indicating that the respiration is both by aerial and aquatic modes. In the laboratory, the snail moves towards the water mark and avoids continuous submersion. T. telescopium also prefers a substratum of fine sand mixed with clay. The snail feeds on the detrital matter and diatoms settled on the substratum.

2.5 ELECTROPHORETIC STUDIES

The pattern of the protein fractions stained by CBB from the foot muscle, ovarian and testicular tissues of C. (C.) cingulata, C. (C.) obtusa and T. telescopium are given in Figs. 18, 19 and 20 respectively.

There are 12, 10 and 14 fractions in the foot muscle of C. (C.) cingulata, C. (C.) obtusa and T. telescopium respectively. Of them 5 fractions in C. (C.) cingulata and C. (C.) obtusa and 4 fractions in T. telescopium are dense. Fast moving fractions are 4 in C. (C.) cingulata, 3 in C. (C.) obtusa and 4 in T. telescopium while intermediate fractions number 4, 4 and 5 respectively. Between

C. (C.) cingulata and C. (C.) obtusa there are 8 common fractions while between the three species there are only 5 common fractions.

In the ovarian tissue, there are 8, 7 and 6 fractions respectively in C. (C.) cingulata, C. (C.) obtusa and T. telescopium. The fractions recorded in the ovary are all represented in the foot muscle except two in C. (C.) cingulata. Of these fractions, there are 2 fast-moving and 2 intermediate fractions in all the three species. Five fractions in C. (C.) cingulata, 3 in C. (C.) obtusa and 2 in T. telescopium, are dense. There are 3 common fractions between the three species.

In the testis, the number of fractions are similar to the female gonad, in the case of C. (C.) cingulata (8), while they are more in C. (C.) obtusa and T. telescopium. Fast moving fractions are 2, 3 and 4 and intermediate moving are 2, 2 and 4 respectively, in the three species. High density fractions are 2, 2 and 3 in C. (C.) cingulata, C. (C.) obtusa and T. telescopium, respectively. Four fractions are common between the three species.

Davis and Lindsay (1967a) suggested that for taxonomic purpose, the band pattern between midway and front (Rm 0.5 to 1.0) are more reliable. Three to eight

such fractions were observed among the three species, of which 3 are common in the foot muscle and 2 in the gonadial tissue.

The pattern of glycoproteins was much simpler in all the species examined (Figs. 21-23). In the foot muscle, there are 4 fractions in C. (C.) cingulata and C. (C.) obtusa while there are six in T. telescopium. Of them, 2 are slow moving and the rest fast moving. There are no intermediate fractions.

In the ovarian tissue the total number of fractions varied from 3 to 5. Fast moving fractions are 2 in C. (C.) cingulata, and one each in C. (C.) obtusa and T. telescopium. In the testis, the total number of fractions varied from 3 to 5 and the fast moving fractions are 2 in all the species.

In the case of glycoproteins, the total number of fractions from midway to front are 2 except in the foot and ovary of T. telescopium and also the ovary of C. (C.) obtusa.

The pherograms of the general protein and glycoprotein in the foot muscle, ovary and testis of C. (C.) cingulata, C. (C.) obtusa and T. telescopium, are given in Fig. 24 and 25, respectively.

To quantify the systematic affiliation between the three species, an attempt has been made based on the

number of protein fractions encountered in any of the two species following Bedford and Reid (1969), as applied by Shahul Hameed(1984). The number of fractions different between any two species was scored. The percentage difference between them was found out from the formula:

$$\frac{\text{Number of fractions different between each pair}}{\text{Total number of fractions present in each pair}} \times 100.$$

The percentage obtained was plotted in Trelli's diagram (Fig. 26).

It was observed from the figure. that in general, the difference between C. (C.) cingulata and C. (C.) obtusa, is from 18 to 23%, while with T. telescopium, it is between 33 and 54%. In the case of glycoproteins also, interspecific differences in the genus Cerithidea, was only 0 to 25%, while the intergeneric difference was 25 to 50%.

The electrophoretic studies reveal, without any doubt, a strong affiliation between the three species at the family level; C. (C.) cingulata and C. (C.) obtusa appear to be closely related and justify their inclusion in the same genus. Between the two species of Cerithidea and T. telescopium, affinity to C. (C.) cingulata is more than to C. (C.) obtusa.

2.6 DISCUSSION

An anatomical study of three species of potamidids shows many similarities. Difference in shell size and sculpture between members of potamidids, was observed by Vermeij (1973) who stated that higher shore forms have slender and larger shells, an adaptation to extreme desiccation and temperature. T. telescopium and C. (C.) obtusa, have larger shells than their counterpart C. (C.) cingulata, which inhabits the low levels confirming the above view.

Dissolution of shell at the apex and the erosion of axial rib found in C. (C.) obtusa, was attributed to high acidic conditions found in the sediment of mangrove and as a means of calcium carbonate conserving mechanism (Vermeij, 1973). Therefore, the difference in shell structure among the members of the same family are due to the influence of the environment.

The external morphology, pallial organs, digestive system, reproductive system, vascular, excretory and nervous systems are all similar in all the three species. The organisation resembles that of lower mesogastropods and corresponds with the description of Littorina by Fretter and Graham (1962). Potamidids bear common characters to the super family Cerithiacea in having a crystalline style,

ciliary mode of feeding and open pallial gonoduct. These are considered as primitive characters and the potamidids are positioned in the lower level of evolutionary ladder.

Driscoll (1971) ascribed the difference in the radular length to the nature of substratum on which the snails live and feed on. More number of teeth and lengthy radula in C. (C.) obtusa indicate that it can feed on coarser particles too.

The morphology of the digestive system in general is similar in all the three species.

The reproductive system in male and female is almost similar except for some details. No external recognition of sex is possible. Woodard (1934) suggested that the similarity in structure and arrangement of gonoducts in males and females in Pleuroceridae, which is a freshwater cerithiacean family, may be because of a fairly recent hermophrodite ancestry. This is true in the potamidids also, sharing a common ancestry. Dazo (1965) described the spermatophore in Goniobasis, a pleuroceriid, which closely resembles that of C. (C.) obtusa.

The open pallial gonoducts described for potamidids are similar to those of other cerithiaceans - Bittium (Johansson, 1947; Fretter and Graham, 1962), Cerithiopsis

(Fretter, 1951); Tympanotonus (Johansson, 1956); Cerithium (Houbrick, 1974b); Rhinoclavis, Pseudovertagus and Clavocerithium (Houbrick, 1978).

Regarding the problem of open pallial gonoducts of cerithiacea, Johansson (1947,'56) pointed out that open glandular grooves with sperm collecting gutter along the edge of the oviducal folds occur in several families with different habits of life e.g., Turritellidae, Cerithiidae, Melaniidae, Pleuroceridae and Potamididae. He opined that such pallial gonoducts were primary characteristic of the group Cerithiacea and were ancestral recurrences of primitive grooves. Fretter (1951) and Fretter and Graham (1962) did not agree with the opinion of Johansson. They suggested that the open condition of the duct and the absence of penis in these mesogastropods were correlated with a long, narrow mantle cavity. In such closely coiled visceral spires there is less space for the right half of the pallial complex. During the breeding season, the presence of a penis in the male and its insertion into the pallial oviduct during copulation would interfere with the efficient functioning of the mantle cavity. Therefore, they concluded that the penis was lost and the spermatophore was transferred to the female through

open ducts, and that the open condition of the duct in such mesogastropods is probably secondary and advantageous. This view may hold good in the case of potamidids also.

The excretory organ, heart and vascular systems, nervous system and sense organs are as in other mesogastropods.

C. (C.) cingulata, is absent in the mangrove probably because of the more acidic conditions of the sediment. The absence of C. (C.) obtusa in the open area may be due to its preference for humid atmosphere than direct exposure to sunlight.

C. (C.) cingulata is found in greater abundance than the other two species. High fecundity and successful adaptation to environmental conditions must have led to successful colonisation of C. (C.) cingulata, in the estuarine environment.

Differences in the protein fractions bring out the taxonomic relation between the three species. Being placed in the same genus, C. (C.) cingulata and C. (C.) obtusa, show a closer alliance. They differed significantly from T. telescopium. The interesting point is about the relationship between C. (C.) cingulata and T. telescopium, on one hand and C. (C.) obtusa and T. telescopium, on the

other. The former two show close affiliation than the latter two.* A perusal of the shell morphology itself brings out this similarity between these species. Both C. (C.) cingulata and T. telescopium, have more than 10 whorls and more conical than C. (C.) obtusa. Decollation is minimum in those two species. The former two species share a common habitat of intertidal substratum, while the latter is a tree-associated form. C. (C.) obtusa is more adapted to air-breathing than aquatic respiration as evidenced by the behaviour of avoiding submersion. On the other hand, C. (C.) cingulata and T. telescopium need periodical submersion and are adapted to aquatic respiration rather than to aerial respiration. So it can be concluded that among the three, C. (C.) obtusa is probably highly evolved than the other two species. It is not out of place to quote here the words of Morton (1967): "Most terrestrial molluscs have early relationships with estuarine or freshwater species and they may share similar adaptations, especially in respiration and reproduction. Thus lack of oxygen in estuarine waters may first lead to aerial respiration. Air breathing in aquatic snails in turn allows eastivation in response to occasional draught. This leads to further adaptations against desiccation and fully amphibious habit

* Similar view was expressed by Kasinathan and Natarajan

develops. With this comes changes in the mode of excretion, leading finally to a complete terrestrial life". This seems to be most true in the case of C. (C.) obtusa.

The salient features of the present study on the potamidids of Porto Novo can be summerised as follows;

1. Three species belonging to two genera viz. C. (C.) cingulata, C. (C.) obtusa and T. telescopium are found in the Porto Novo area.

2. Shell sculpture is different in these species. In C. (C.) cingulata both axial ribs and spiral ridges are prominent. In the case of C. (C.) obtusa, the axial rib though eroded, is better developed than spiral ridges, while in T. telescopium spiral ridges and spiral grooves are found.

3. External morphology of the body and pallial organs are similar in all the three species. Pallial organs include osphradium, ctenidium, hypobranchial gland, alimentary tract and the gonoduct.

4. Alimentary system includes buccal cavity enclosing jaws, odentophore, radula, radular sac and salivary gland, oesophagus, stomach, intestine and rectum. A style sac enclosing the crystalline style is common. The digestive gland is prominent. Radular teeth differ in shape and number of rows between the species.

5. Reproductive system includes gonad, gonoduct and open pallial gonoduct. No copulatory organ is present. Two types of sperms, eupyrene and apyrene, are present. Spermatophore (for transfer of sperms) is formed.

6. Excretory, circulatory and nervous systems are similar in all the three species and are in the same pattern as for Mesogastropoda in general.

7. C. (C.) cingulata is found in the intertidal area between MTL and LTL. C. (C.) obtusa inhabits only the mangrove forest. T. telescopium is found in the intertidal region from MTL to HTL. Thus, the three species occupy different levels in the intertidal zone.

8. Pattern of protein fractions (both general and glycoproteins) indicates closer association between C. (C.) cingulata and C. (C.) obtusa at interspecific level and both differ from T. telescopium. C. (C.) cingulata shows more affinity to T. telescopium.

9. C. (C.) obtusa appears to be more highly evolved than the other two species.

LIST OF ABBREVIATIONS USED IN FIGURES

alg	:	albumen gland
an	:	anus
apw	:	apical whorl
blsi	:	blood sinus
cg	:	capsule gland
chc	:	cephalic haemocoel
cm	:	columellar muscle
cpg	:	cerebro-pleural ganglion
cs	:	crystalline style
ct	:	ctenidium
dg	:	digestive gland
e	:	eye
go	:	gonad
he	:	heart
hg	:	hypobranchial gland
in	:	intestine
inh	:	inhalent siphon
k	:	kidney
la	:	lateral tooth
ll	:	lateral lamina
ma_1	:	marginal teeth
ma_2		
mc	:	mantle cavity
md	:	median tooth
me	:	mantle edge
ml	:	median lamina
mp	:	metapodium
ng	:	pallial siphonal eye

o	:	oviduct
oc	:	oral cavity
od	:	odontophore
odg	:	oviduccal groove
oe	:	oesophagus
op	:	operculum
osp	:	osphradium
ov	:	ovary
pdg	:	pedal ganglion
pgd	:	pallial gonoduct
prg	:	prostate gland
prp	:	propodium
rd	:	radula
re	:	rectum
rs	:	radular sac
ser	:	seminal receptacle
sg	:	salivary gland
sgr	:	seminal groove
sn	:	snout
spg	:	sperm collecting gutter
ss	:	style sac
st	:	stomach
t	:	testis
te	:	tentacle
vd	:	vas deferens

Fig. 5. C. (C.) cingulata, female with shell removed exposing mantle, visceral mass and associated organs.

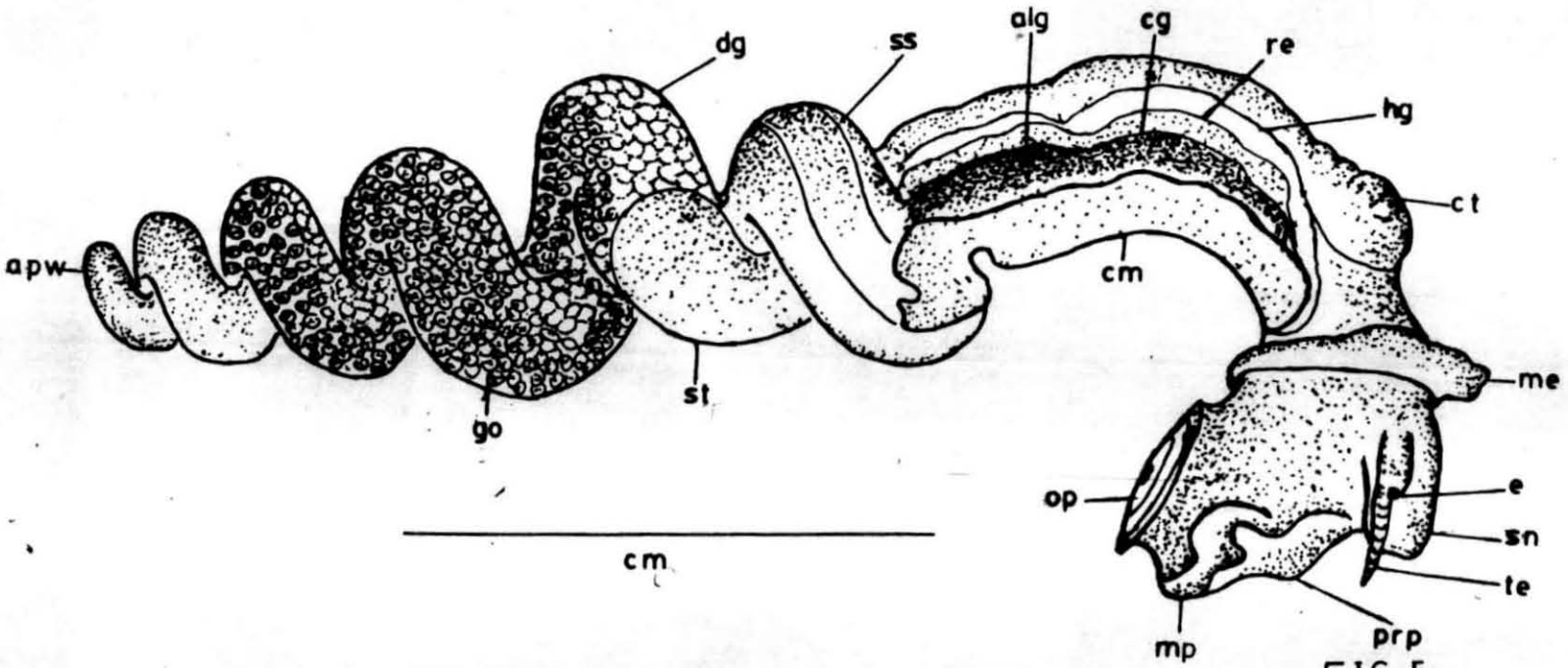


FIG 5

Fig. 6. C. (C.) obtusa, female with shell removed exposing mantle, visceral mass and associated organs.

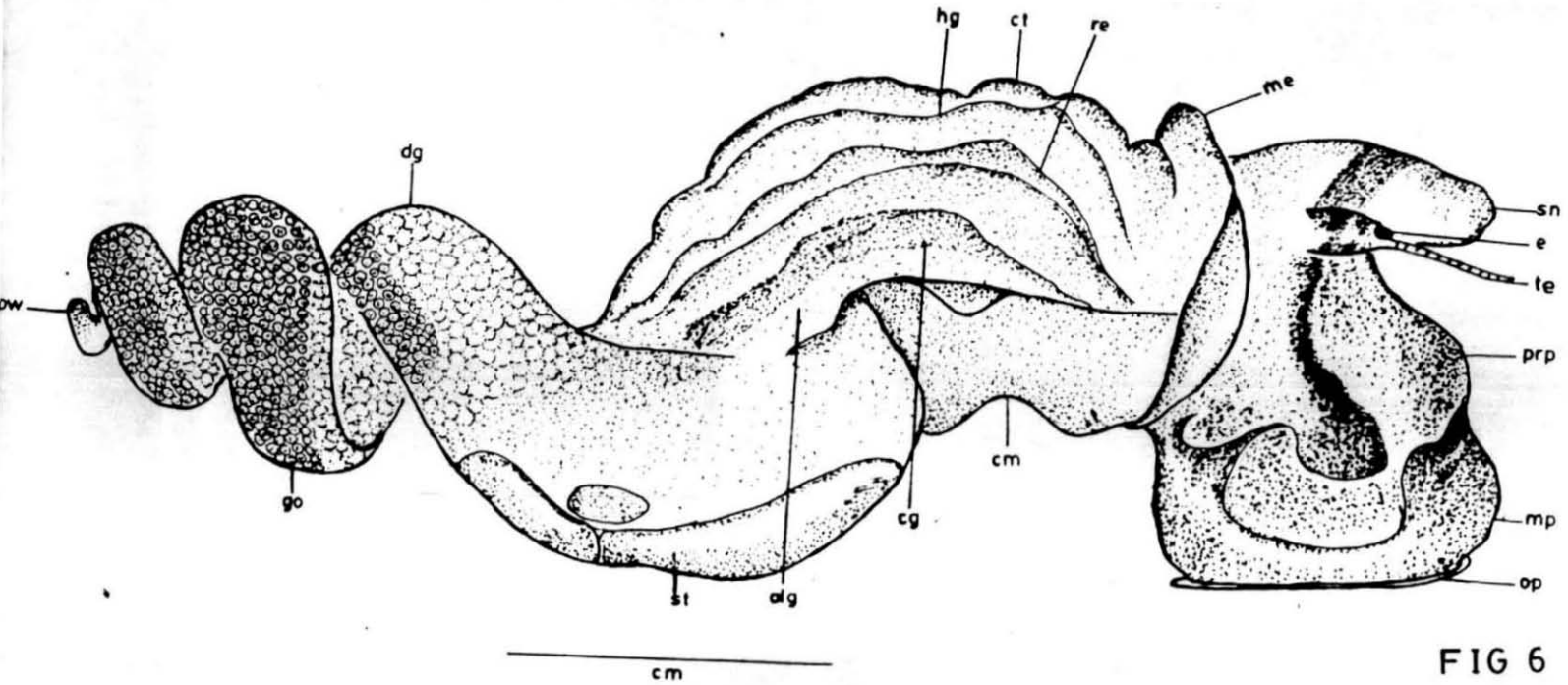
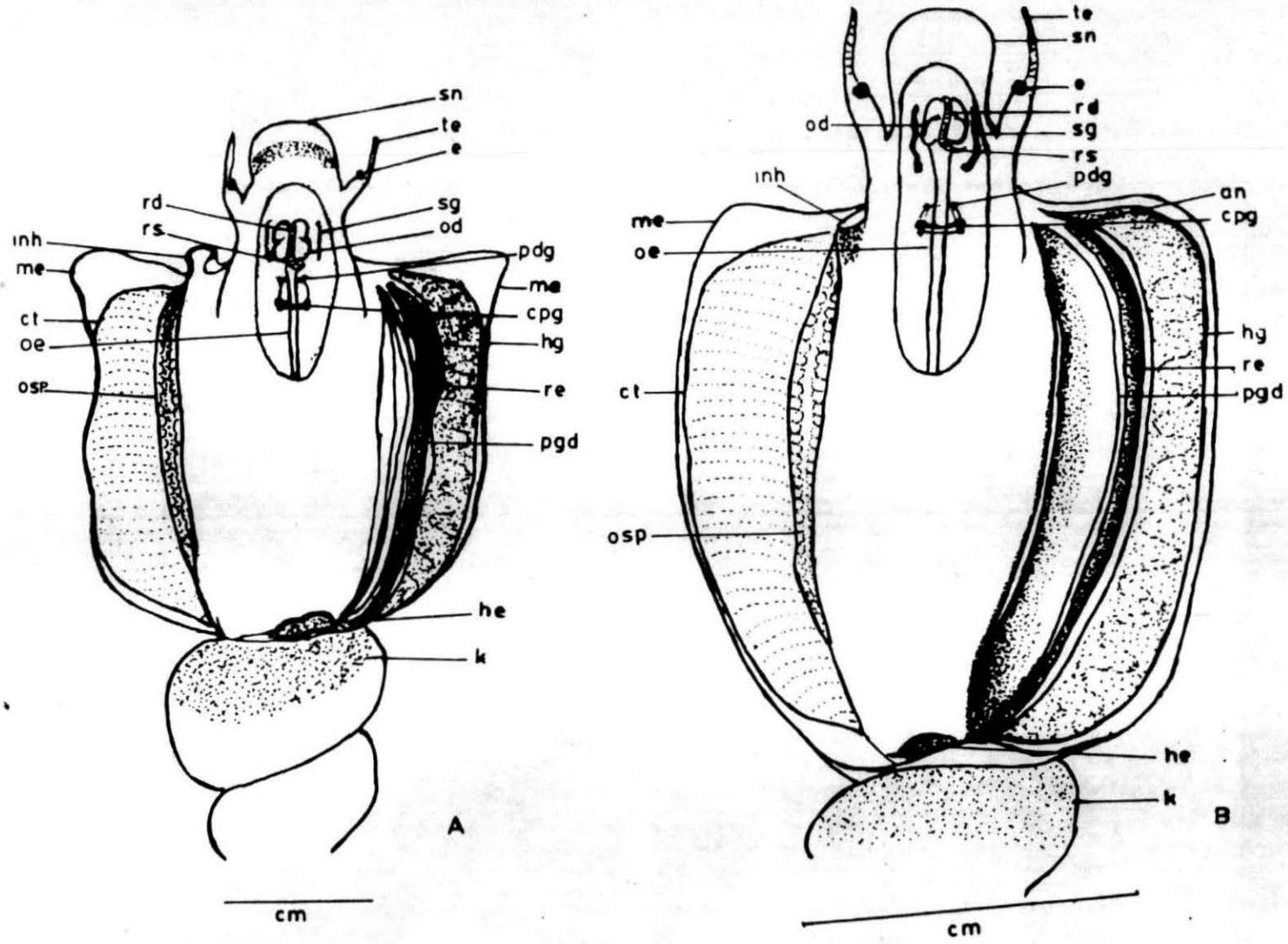


FIG 6

Fig. 7. A) C. (C.) obtusa

B) C. (C.) cingulata

Mantle skirt medially cut; two halves deflected laterally. Buccal cavity opened mid-dorsally exposing anterior alimentary tract and nerve ring.


sn
te
e
rd
sg
od
rs
inh
pdg
me
me
ct
cpg
oe
hg
osp
re
pgd
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k
A
cm
te
sn
e
rd
od
sg
rs
pdg
inh
an
me
cpg
oe
hg
re
ct
pgd
osp
he
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B
cm

FIG 7

Fig. 8. C. (C.) cingulata, T.S. through anterior edge of the mantle cavity.

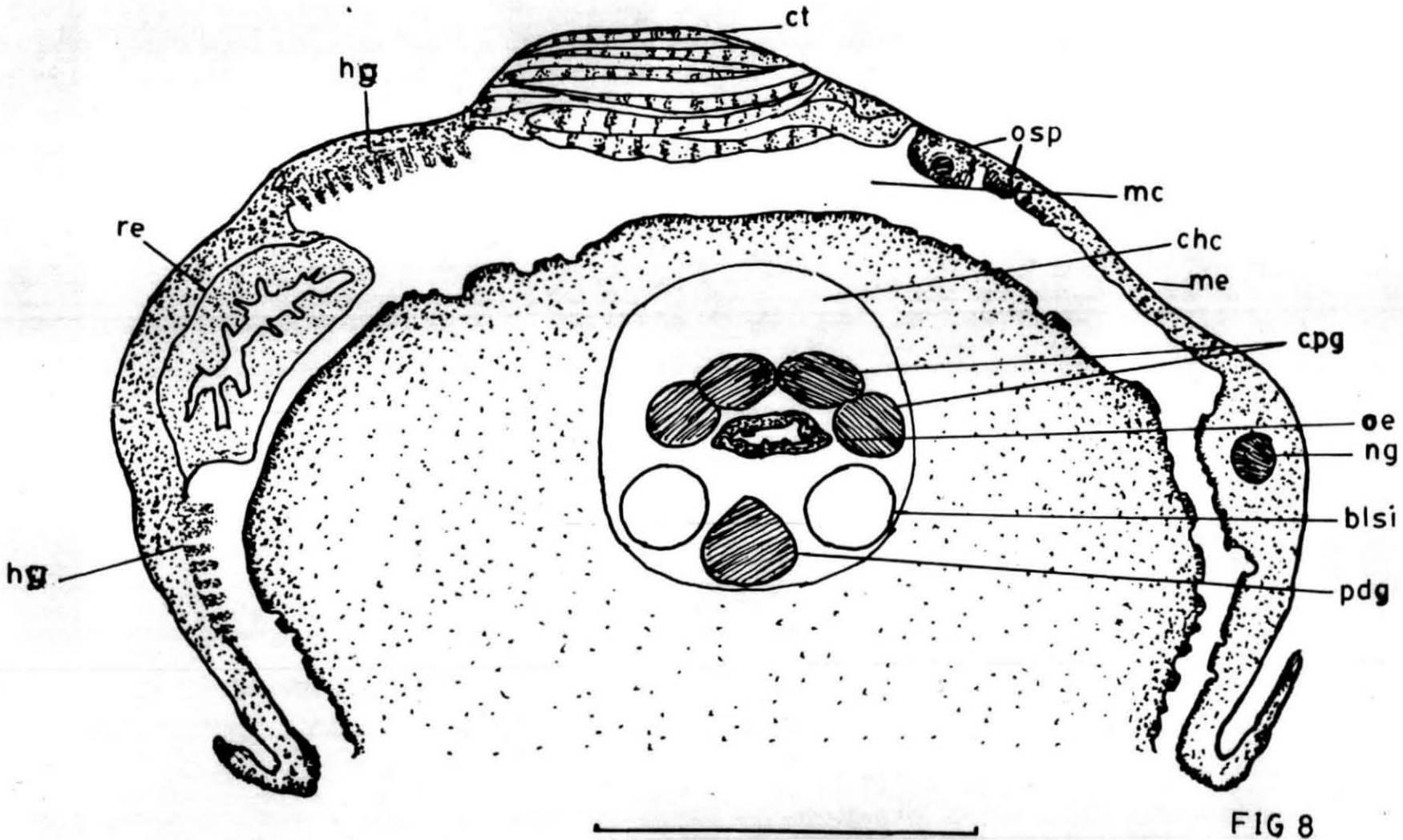


FIG 8

Fig. 9. Digestive system of C. (C.) obtusa

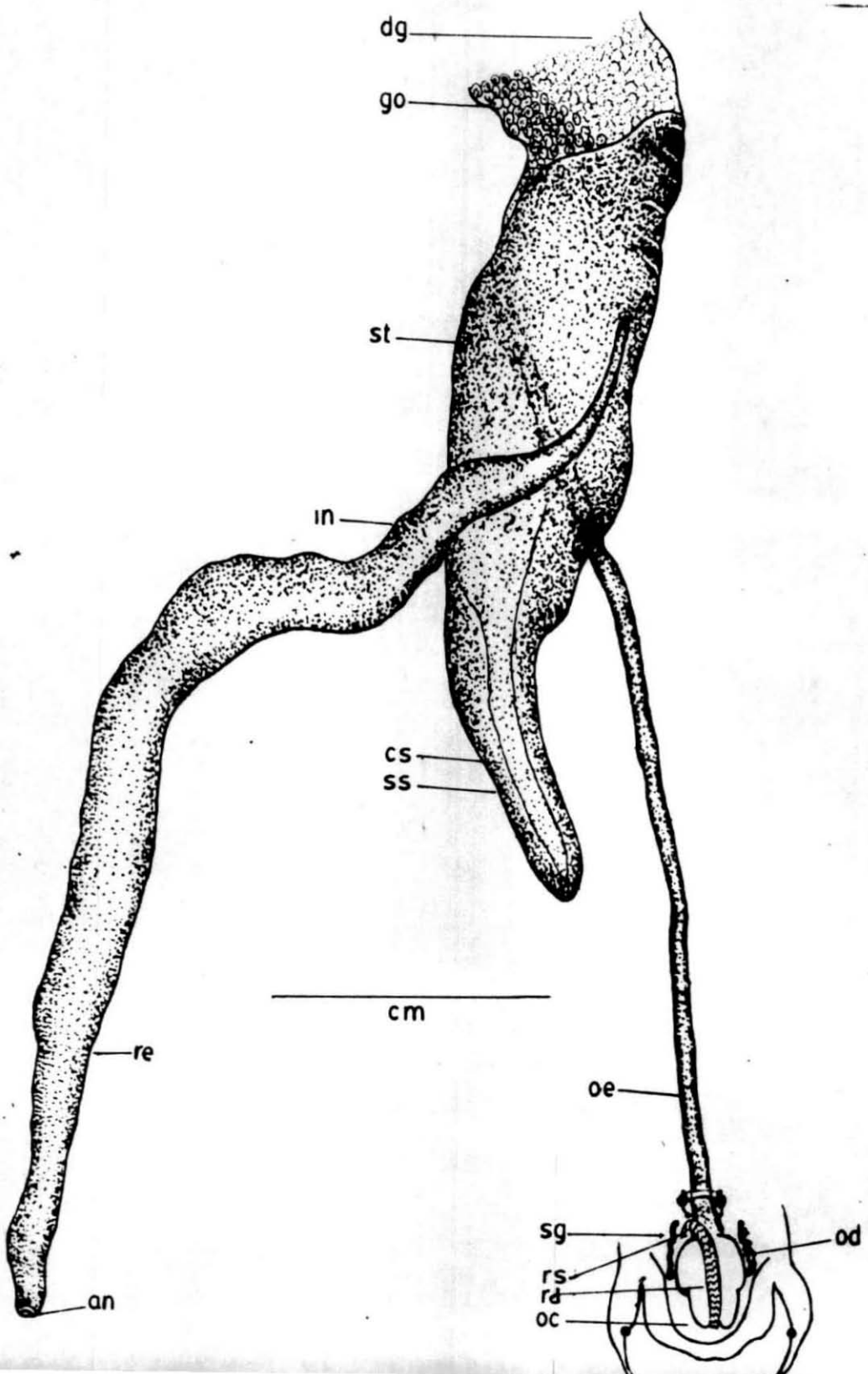
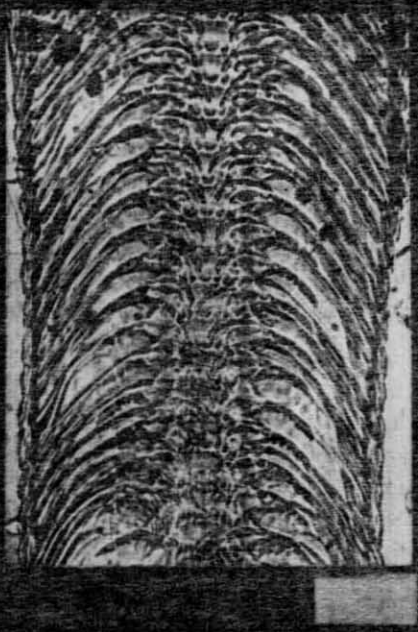

dg
go
st
in
cs
ss
cm
re
oe
sg
od
rs
rd
oc
an

Fig. 10. Radula of C. (C.) cingulata. x150

Fig. 11. Radula of C. (C.) obtusa. x150

Fig. 12. Radula of T. telescopium. x150



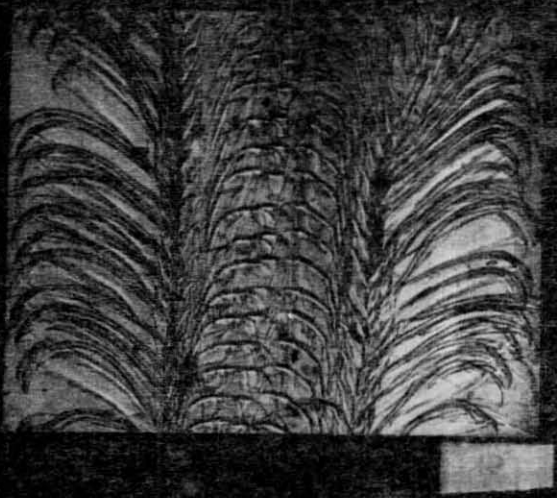
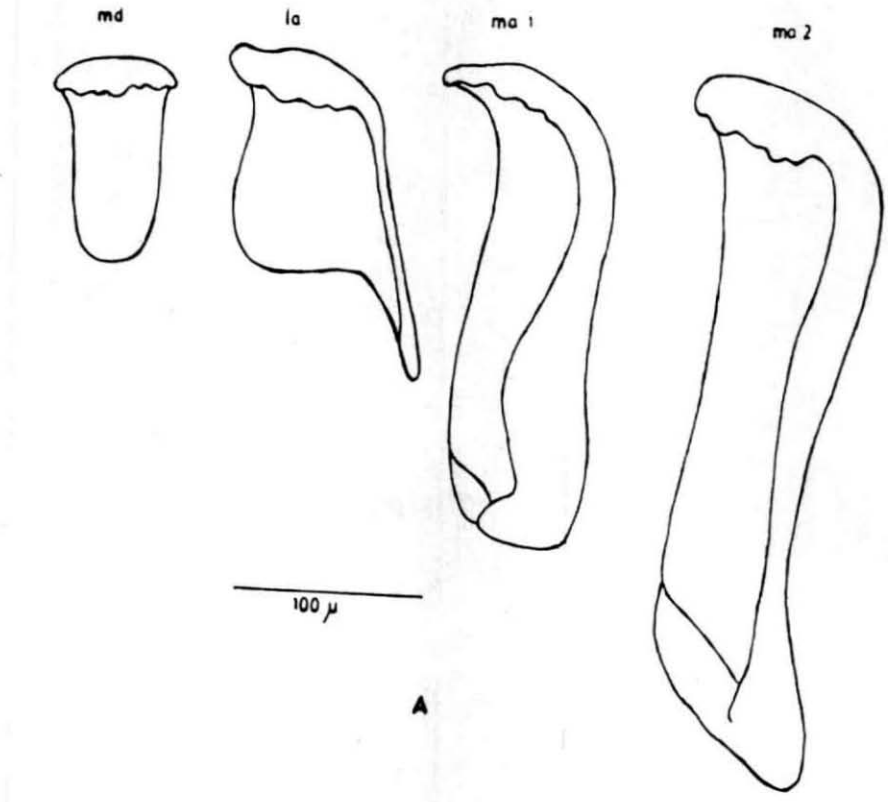


Fig. 13. Radular teeth of

A) C. (C.) obtusa

B) T. telescopium



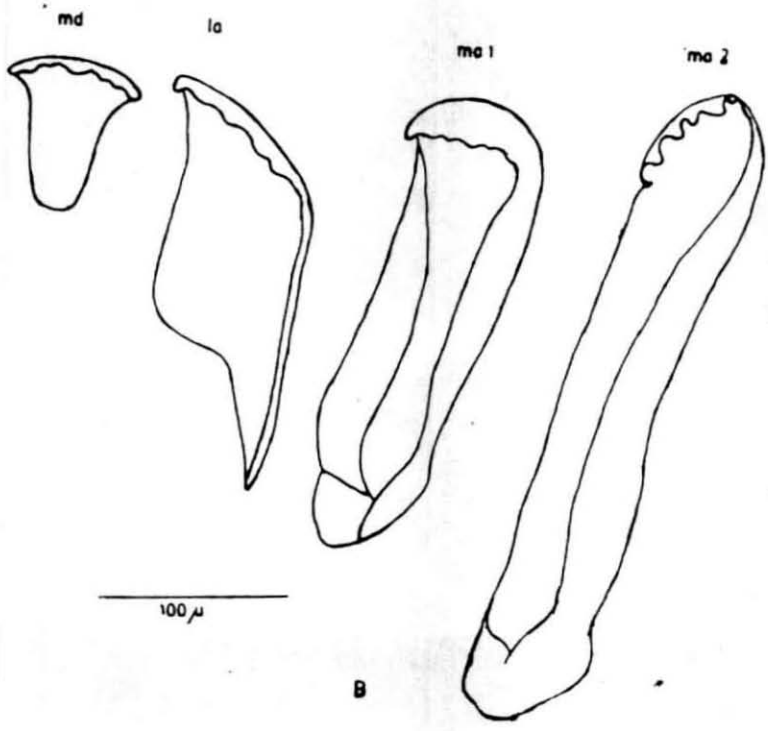


FIG 13

Fig. 14. C. (C.) obtusa

A) Male reproductive system

B) Female reproductive system

C) Eupyrene sperm

D) Apyrene sperm

E) Spermatophore

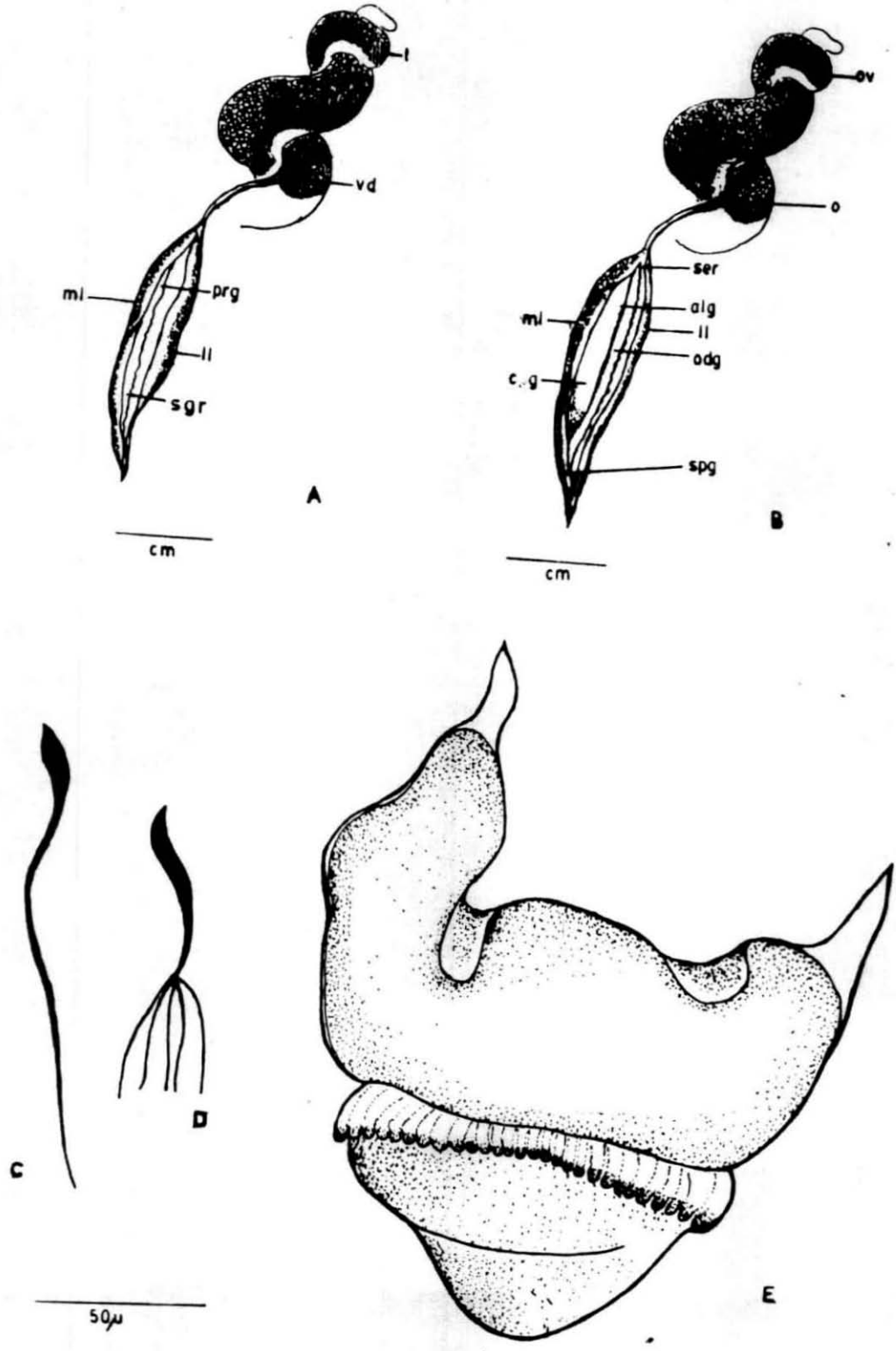


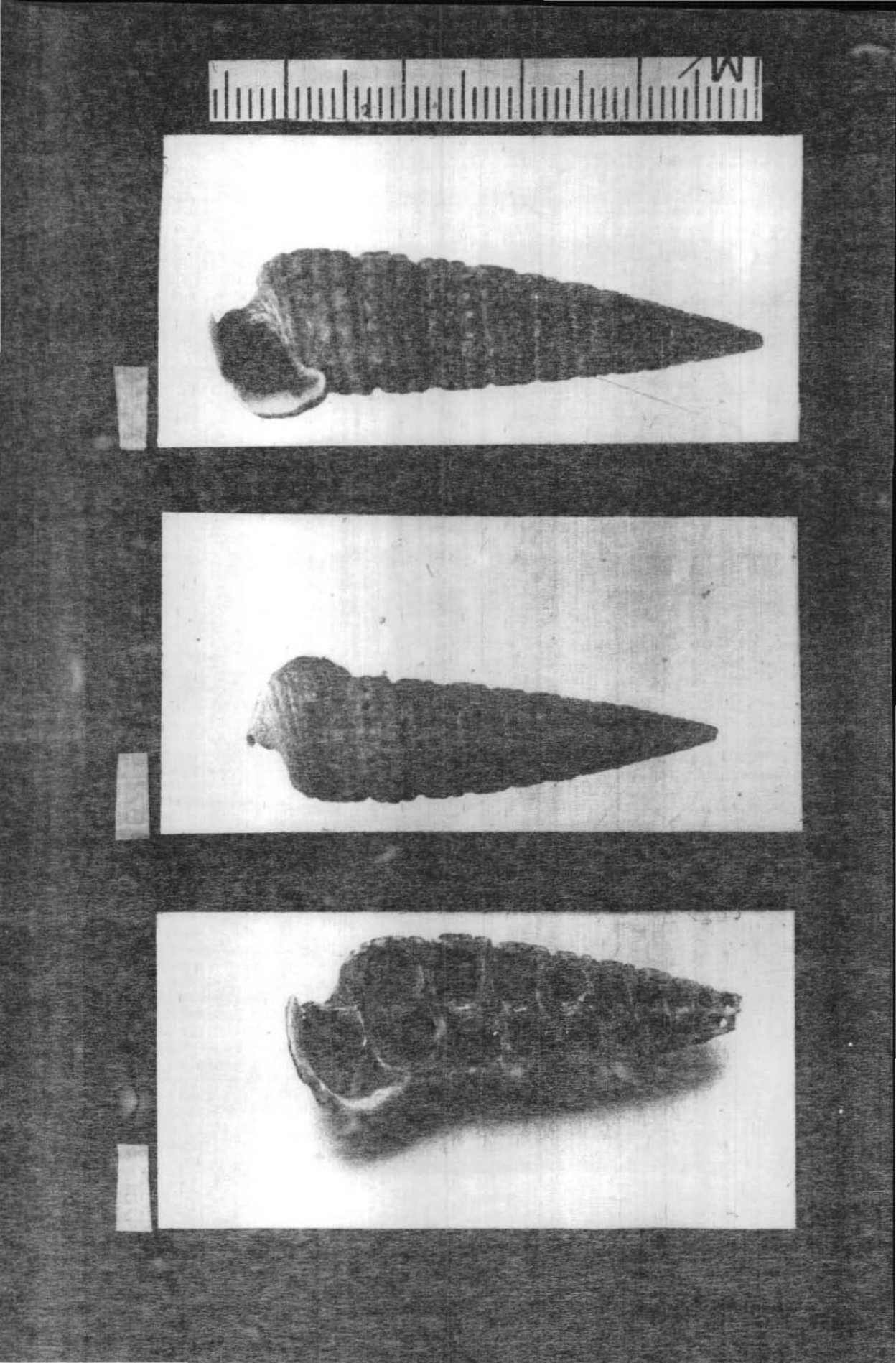
FIG 14

Fig.15. C. (C.) cingulata

A) Apertural view

B) Abapertural view

C) Longitudinal cut exposing columella

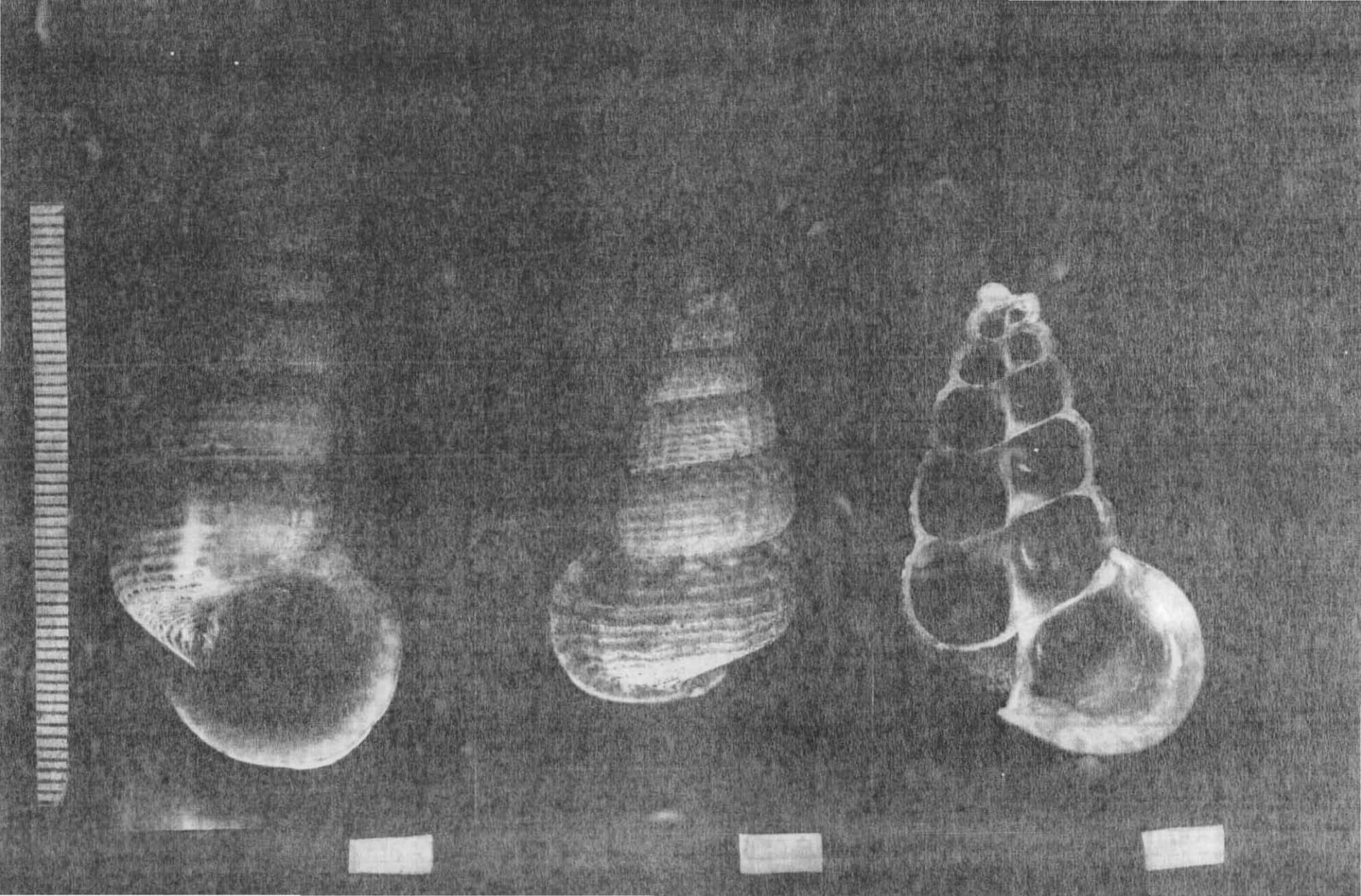


ig. 16. C. (C.) obtusa

A) Apertural view

B) Abapertural view

C) Longitudinal cut exposing columella

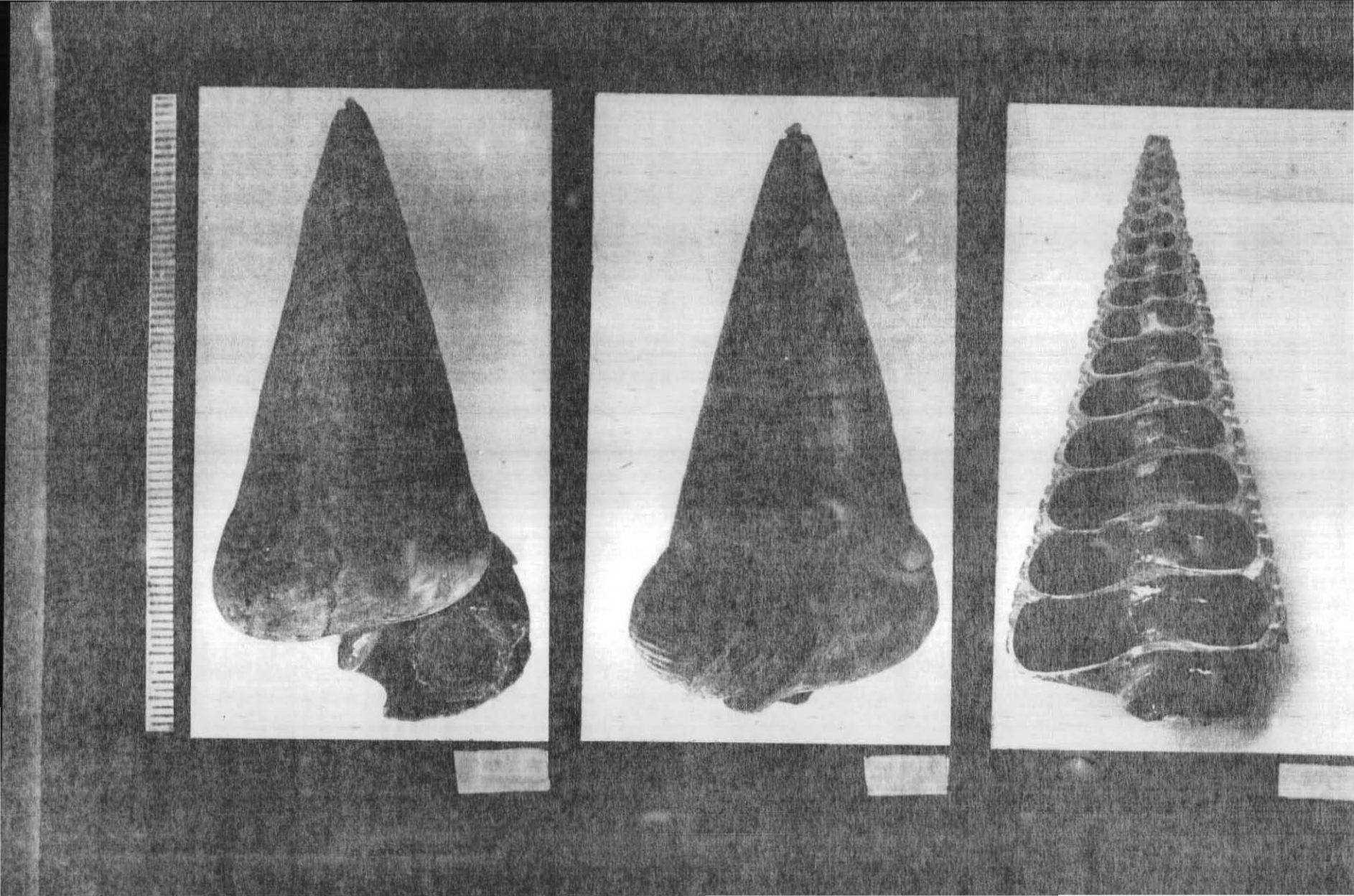


g. 17. T. telescopium

A) Apertural view

B) Abapertural view

C) Longitudinal cut exposing columella and columellar fold



g. 18. Protein fractions in the foot muscle of potamidids (electrophorogram).

g. 19. Protein fractions in the ovarian tissues of potamidids (electrophorogram).

g. 20. Protein fractions in the testicular tissues of potamidids (electrophorogram).

C : C. (C.) cingulata

O : C. (C.) obtusa

T : T. telescopium

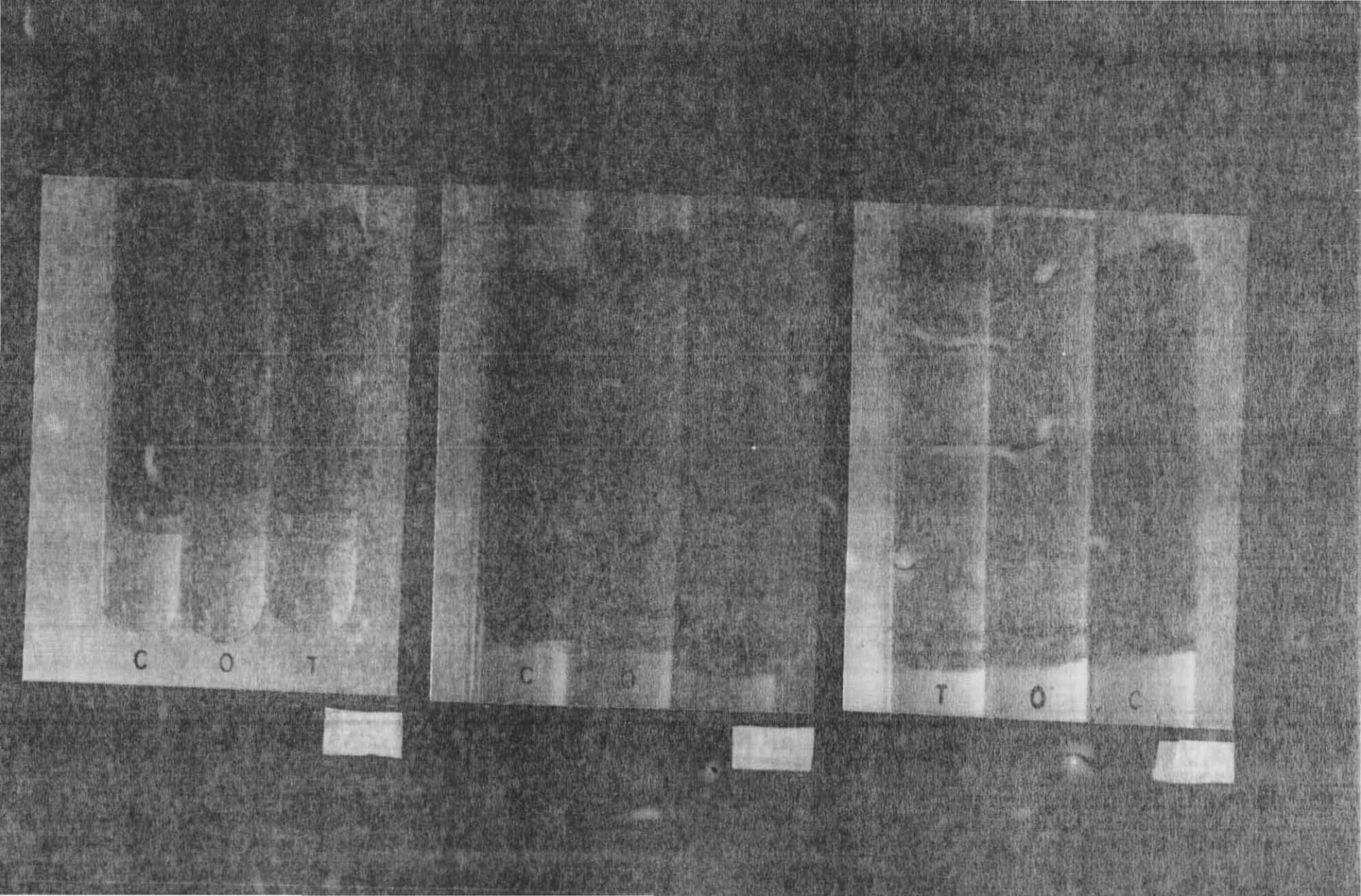

C O T
C O
T O C

Fig. 21. Glycoprotein fractions in the foot muscle of potamidids (electrophorogram).

Fig. 22. Glycoprotein fractions in the ovarian tissues of potamidids (electrophorogram).

Fig. 23. Glycoprotein fraction in the testicular tissues of potamidids. (electrophorogram)

C : C. (C.) cingulata

O : C. (C.) obtusa

T : T. telescopium

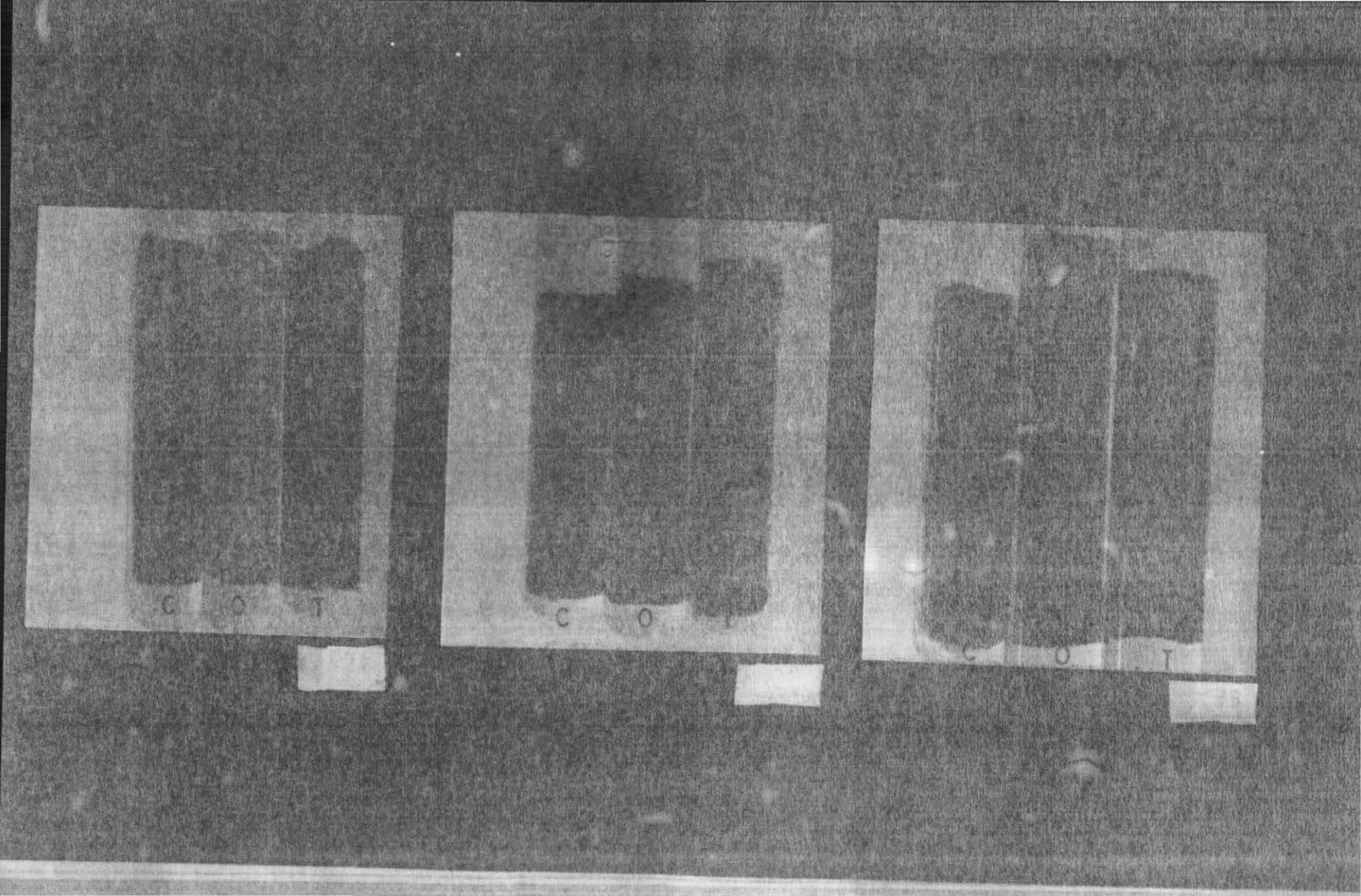

C O T
C O
C O T

Fig. 24. Electropherograms of protein fractions in the foot muscle, ovarian and testicular tissues of potamidids.

Fig. 25. Electropherograms of glycoprotein in the foot muscle, ovarian and testicular tissues of potamidids.

C : C. (C.) cingulata

O : C. (C.) obtusa

T : T. telescopium

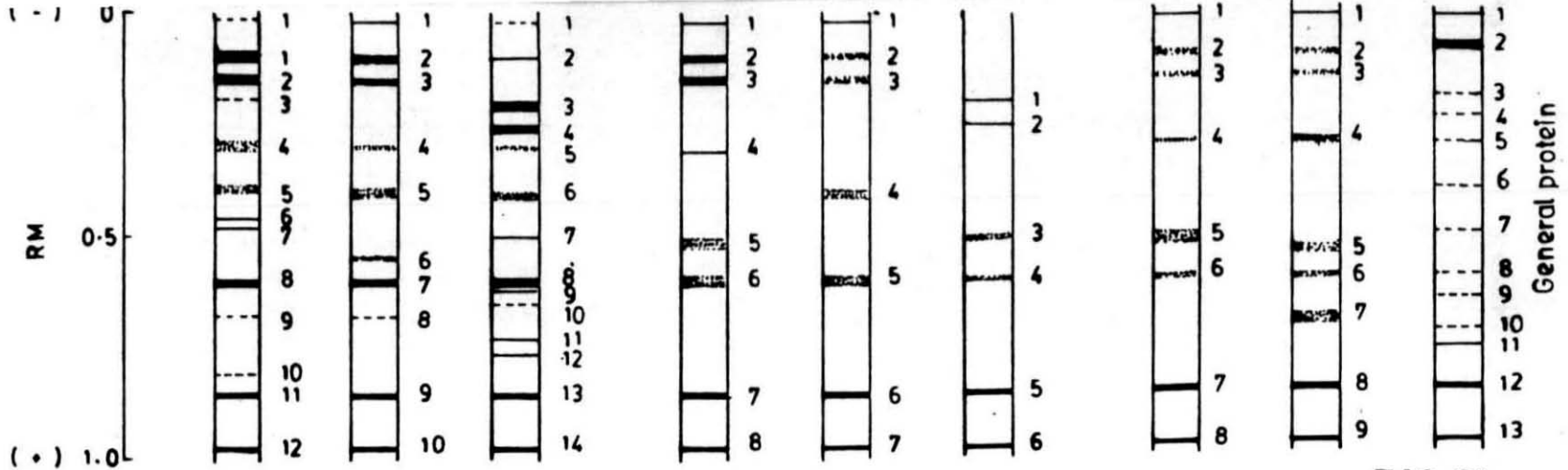

RM
0·5
(-) 0
(+) 1.0
General protein

FIG 24

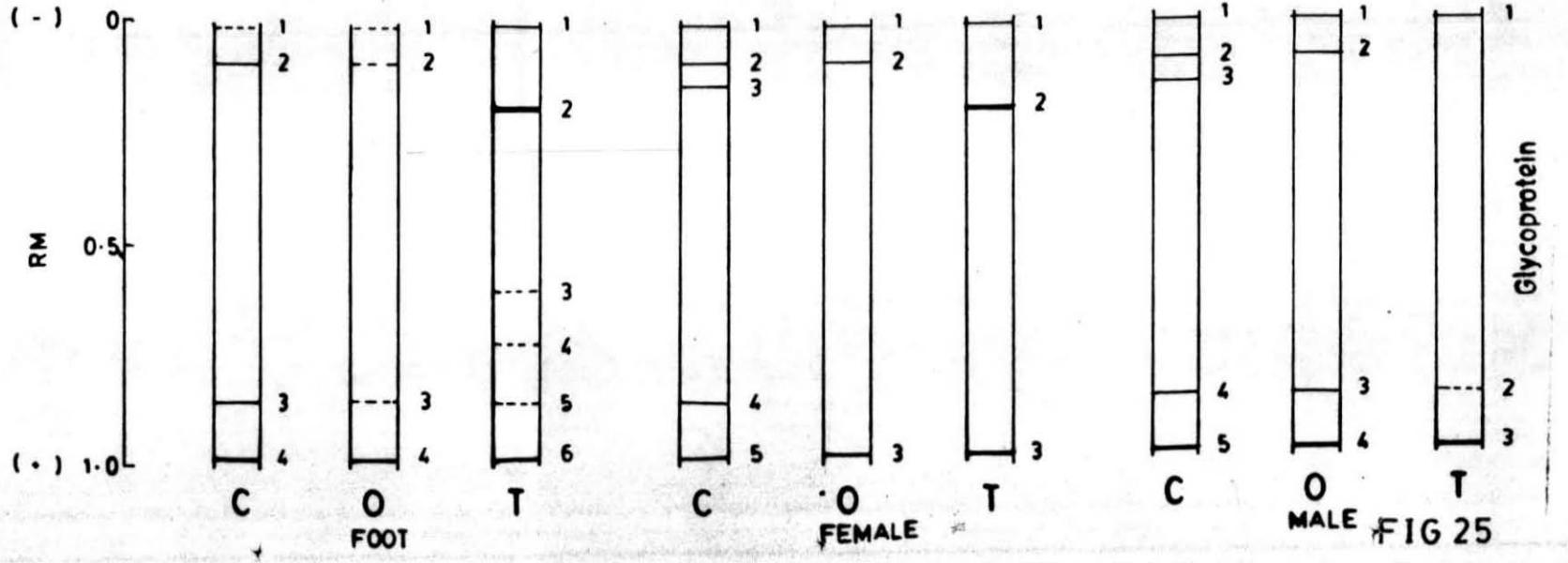

RM
0·5
(-) 0
(+) 1.0
C
O
T
FOOT
FEMALE
MALE
Glycoprotein

FIG 25

Fig. 26. Trelli's diagram showing the differences (in percentage) in general and glycoproteins between the potamidids.

C.C.C. : C. (C.) cingulata

C.C.O. : C. (C.) obtusa

T.t. : T. telescopium

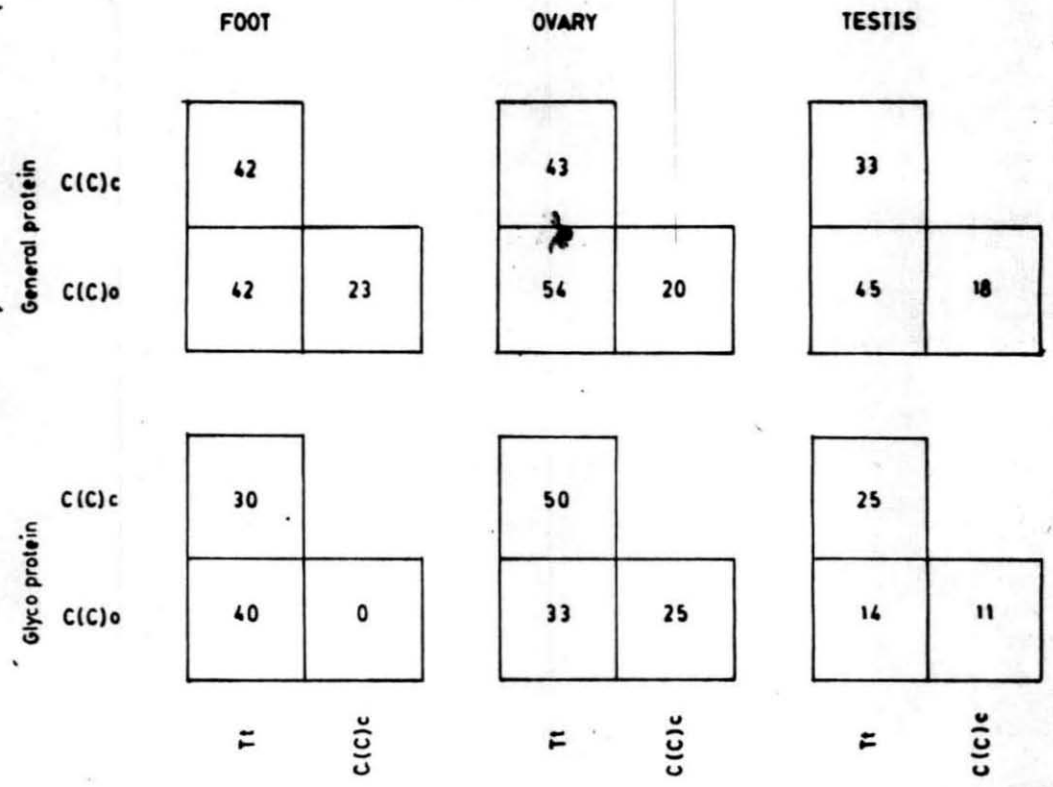

FOOT
OVARY
TESTIS
General protein
C(C)c
C(C)o
42
42
23
43
54
20
33
45
18
Glyco protein
C(C)c
C(C)o
30
40
0
50
33
25
25
14
11
Tt
C(C)c
Tt
C(C)c
Tt
C(C)c

FIG 26

3. ECOLOGY AND DISTRIBUTION PATTERN OF THE POPULATION

3.1 ECOLOGY OF THE STUDY AREA

3.1.1 Introduction

The estuarine ecosystem is a dynamic one since it is directly subjected to conglomerate influences of marine, terrestrial and freshwater elements and is the meeting place of neritic and fluviatile waters. The tidal influence and the flood water run off from land through the river and estuary, lead to the development of unique conditions prevailing therein. Essentially, these two forces interact and the characteristics of estuary is reflected on the balance attained by these forces. In most of the estuaries in tropics, especially in Peninsular India, the environmental conditions are governed by short term changes due to tides and seasonal changes from monsoonal cycles (Sankaranarayanan and Qasim, 1969).

A knowledge of the environmental parameters of estuary is thus an essential prerequisite to understand the composition of its inhabitants, their distribution, dispersal and relative zonal abundance within the vast and interior areas of the estuary. Cerithidea (Cerithideopsilla) cingulata, being an intertidal organism, is exposed to

physical variations such as slope of the shore, wave action, tidal flow, atmospheric, sediment and water temperatures, salinity, dissolved oxygen, pH of the substratum as well as water, organic carbon and particle size of the sediment on which it subsists. Influence of some of these environmental parameters on estuarine gastropod populations has been well studied already. Gowanloch and Hayes (1927), Brockhuysen (1940), Arnold (1957,'72), Berry (1961), Kinne (1963,'64) and Fenchel (1975a,b) have stressed the importance of salinity in the estuarine environment. Newell (1965), Franz (1976), Wells (1978,'80) and Balaparameswara Rao and Sukumar (1981) stated that the nature of sediment influenced the benthic population greatly. Organic carbon was observed to be another factor influencing the distribution of detrital feeders (Crisp, 1969), while surface and sediment temperature, dissolved oxygen and pH play some role in determining the distribution, population density as well as feeding, growth and reproduction.

A comprehensive study involving the environmental parameters and the population of estuarine gastropods is wanting from Indian waters. Balaparameswara Rao and Sukumar (1982) provided some information on the distribution pattern of C. (C.) cingulata and the ecological factors contrived

with this pattern in the Nizampatnam canal of Andhra coast. Olivia (1981), while studying the intertidal animals, made some observations on the occurrence of the same species in the Vellar estuary. No detailed study on the distribution and the long term changes in the population of C. (C.) cingulata in the Vellar estuary has however been made. Therefore, in this present study observations on salinity, temperature, dissolved oxygen, pH and nature of substratum, along with associated fauna and flora in the three study sites have been made for a period of two years from September 1982 to August 1984.

3.1.2 Material and methods

A preliminary survey was made in September 1982 to record the distribution pattern of C. (C.) cingulata in the Vellar estuary. The snail was found to be dense along the main channel, in the creeks of the estuary and in the lagoon. Regular sampling was done for 24 months at the three sites, mentioned in Chapter 1. Samples were collected around full-moon day once in a month. Along with this, water and sediment samples were also collected. Simultaneously, surface, atmospheric and sediment temperatures were also

recorded. Temperature was recorded with a celsius thermometer upto 0.1°C precision. The pH was measured with a pH meter (Elico Model LI-10). Salinity and dissolved oxygen were estimated by argentimetric titration and by modified Winkler's method respectively (Strickland and Parsons, 1972). One hundred litres of water was filtered through a No.25 (Bolting silk) plankton net to collect plankton. Both phytoplankton and zooplankton thus collected were fixed in 5% formalin (neutral) for qualitative and quantitative analyses through a Utermohl's inverted plankton microscope.

Analysis of dried samples of sediment was made for estimating the percentage of sand, silt and clay following the standard (combined) sieving and pippette method of Krumbein and Pettijohn (1938). The textural class of the sediment was ascertained as recommended by the United States Department of Agriculture (Anon., 1951). Total organic carbon in the sediment was estimated by the method of el Wakeel and Riley (1957) using chromic acid digestion and titrating against Ferrous ammonium sulphate using Phenanthrolein as indicator. Since all the collections were made in shallow areas, slight differences if any, between bottom and surface values of salinity, temperature and dissolved oxygen were normally not taken into consideration.

Records were also maintained on the floral composition, molluscan fauna, epizoic forms on C. (C.) cinguiata, quantity of dead shells and hermit crabs occupying such shells.

Monthly rainfall data for the period of study was obtained from the Meteorological section located in this Centre (Courtesy : Meteorological Department, Government of India).

3.1.3 Results

(a) Rainfall:

The rainfall in peninsular India depends mainly on two monsoon seasons viz., the southwest monsoon (June-September) and the northeast monsoon (October-December). Porto Novo coast experiences heavy northeast monsoonal downpour with comparatively very little precipitation during the southeast monsoon season.

Monthly rainfall during the two year study period showed a contrasting picture (Fig.27). During the first year the total rainfall was 1004.6 mm whereas in the second year, it was 1962.2 mm (at an average of 83.7 mm and 163.5 mm per month respectively). In the first year, the rain was

restricted to the normal monsoon period (October-December) while in the second year the precipitation prolonged till April which was unusual for the area. The rainfall of 503.5 mm in December, 1983, 291 mm and 255 mm in February and March 1984 were records for these months (for the last 15 years). On the otherhand the rainfall was low in the first year and it may be significant to add that 1982 was a severe draught year for the whole of Tamil Nadu.

(b) Temperature:

Atmospheric, surface and bottom temperatures recorded at the three sites during the period of observation are given in Fig.28.

Atmospheric temperature varied between 24 and 35°C in all the three sites. High temperature was recorded in summer and low values during monsoon and postmonsoon (January-March). Water temperature and bottom temperature varied between 24 and 32°C. Fluctuations in these factors closely followed that of atmospheric temperature, in that high values were recorded in summer and low values during monsoon and postmonsoon.

(c) Salinity:

Variations in salinity are given in Fig.29. The

low value of 1.22‰ was recorded in October 1983 at Site III and the maximum of 35.75‰ was recorded at Site I in May 1983. Comparatively high salinity prevailed in Site I than in Sites II and III. This can be attributed to the Site I being in close proximity to the sea. Thus, nearly sea water condition existed at Site I from September 1982 to September 1983 because of low rainfall in 1982. Salinity values were low during the monsoon period of 1982, but gradually increased from January 1983 to reach the neritic condition by April. But in 1984, the low saline condition continued till May because of heavy precipitation. High salinity values in summer can be attributed to the influx of neritic water and also to poor freshwater discharge into the estuary.

(d) Dissolved oxygen:

Dissolved oxygen content recorded in the three sites during different months is illustrated in Fig. 30. The values ranged from 3.29 (June 1984) to 5.97 ml/l (July 1984) in Site I; 3.7 (June 1983) to 5.90 ml/l (April 1984) in Site II and from 3.19 (May 1984) to 6.49 ml/l (October 1983) in Site III. Comparatively low values were recorded during premonsoon and monsoon months.

(c) Hydrogen-ion concentration (pH):

The pH of water and sediment was observed to be alkaline (Fig.31). The range of pH in water samples was 7.5 - 8.3 in Site I; 7.9 - 8.4 in Site II and 7.9 - 8.3 in Site III. The pH of the sediment varied from 7.5 to 8.2 in Site I; from 7.2 to 8.2 in Site II and from 7.1 to 8.3 in Site III. Low pH values were noted during September-January (1982-'83) in mud samples.

(f) Organic carbon in the sediment:

Monthly variations in the organic carbon content of the mud at three sampling sites are shown in Fig.32. Variations in organic carbon was from 3.1 to 14.2 mg/g at Site I; from 6.3 to 17.3 mg/g at Site II and from 6.3 to 12.9 mg/g at Site III. Comparatively high values were recorded at Site II followed by Site III and the values were the least at Site I. Seasonwise, comparatively low values were recorded during monsoon than during other seasons.

(g) Sediment composition:

Percentage composition of sand, clay and silt particles and the nature of the substratum at Sites I, II and III are given in Tables 1, 2 and 3, respectively. The nature of the substratum was mostly sandy at Sites I and III,

but clayey-sand at Site II. Percentage of sand particles increased during the rainy season at Site II, while the percentage of clay increased in months of low rainfall.

(h) Plankton:

The checklist of zooplankton and phytoplankton in the Vellar estuary is given in the works of Subramanian (1981), Chandran (1982) and Sivakumar (1982). They also dealt with species succession, diversity, richness and evenness. Therefore, no detailed study on species composition was attempted in the present study. Total phytoplankton and zooplankton density/m^3 and percentage composition of the gastropod veliger in the zooplankton population at the three sites are only given in the present account (Tables 4 and 5, respectively).

Among the phytoplankters, Asterionella japonica, Coscinodiscus jonesious, Biddulphia mobiliensis, Chaetoceros curvisetum, Pleurosigma elongata, Thalassiothrix forcheenfeldii, Navicula rostellata, Ceratium furca, Gonyalux sp. and Peridinium depressa formed the major constituents, during pre- and postmonsoon months, while Chaetoceros sp., Rhizosolenia cochlea, Navicula sp., Ceratium tripos and Anabena sp., Oscillatoria sp., Ulothrix sp. and Spirogyra sp. were predominant during summer and monsoon months respectively.

Among the zooplankton, copepods and crustacean larvae were important constituents during major part of the study period. Copepods were represented by Oithona sp., Acartia sp., Paracalanus sp., Euterpina sp., Evadne sp., Coryaceas sp. and Macrosetella sp. Other crustaceans were Lucifer sp., larval zoea, megalopa of crabs and postlarvae of prawns. Tintinnids formed major part of protozoans represented in the zooplankton samples. The rotifer Brachionus sp. occurred only during monsoon when the salinity was low. Among the coelenterates, Eirene sp., and Dipheus sp. were more common. Sagitta spp. were recorded only in summer when salinity was high. Eggs and larvae of the fishes Ambassis, Stolephorus, Elops, Leiognathus, mullets and Hilsa sp. were recorded in substantial quantity from the zooplankton samples during pre- and postmonsoon seasons.

At Site I, the phyto- and zooplankton populations were higher than in other two sites. Two peaks were evident in zooplankton during the pre- and postmonsoon seasons, while phytoplankton peak was observed during summer. Gastropod veligers were present in plankton all through the year except during monsoon, with a maximum during postmonsoon. Highest percentage of veligers (38.5%) in zooplankton was recorded during February 1984.

In site II, zooplankton density was low, but phyto plankton was more than in Site III. Trend of productivity is similar to Site I, with two peaks in zooplankton and a summer peak in phytoplankton. Occurrence of veliger larvae was also similar to that of Site I and the maximum was noted in April 1984.

At Site III, maximum quantity (1,47,300) of zooplankton was observed in October 1983 and the lowest (6,400) during December 1982. When compared to zooplankton, abundance of phytoplankton was poor. Seasonally, premonsoon months recorded maximum numbers of zooplankton, while during summer, the phytoplankton was more. Gastropod veligers were present throughout the year except during monsoon and the highest was in September 1982 (premonsoon) and February 1983 (postmonsoon).

(i)Associated fauna and flora:

Along with the population of C. (C.) cingulata, floral and faunal compositions were also observed.

(i)Macrovegetation: At Site I, the algae Chaetomorpha sp., Padina sp., Enteromorpha compressa, Ulva lettuce, Codium sp. and Gracilaria sp. were abundant. At Site II, Enteromorpha compressa was dominant. Filaments of Cladophora sp. were also observed during monsoon and postmonsoon. At Site III,

the sea grass, Halodela pinifolia and the flowering plant Halophila ovalis were most common in the intertidal region. At lower levels, heavy growth of Enteromorpha compressa could be observed.

(ii)Molluscan fauna: Among molluscs, C. (C.) cingulata was the dominant macrofauna in all the three sites. Associated molluscan fauna included the gastropods Cerithium coralium, Clithon oulaniensis, Natica sp., Nassa stolata, Littorina scabra, L. undulata, Hymnaea sp., Terebra sp. and Umbonium vestiarium and the bivalves Meretrix casta, M. meretrix, Katelysia opima, Tellina sp., Psammobia sp., Sanguinolaria diphos, Solen sp., Laternula sp., Crassostrea madrasensis, Saccostrea gryphoides, Modiolus sp., Anadara granosa, A. rhombea and Donax sp. were commonly found in the intertidal area of Site I. At Site II, besides C. (C.) cingulata, a small population of another potamidid Telescopium telescopium was present in addition to bivalves like M. casta, Modiolus sp. and C. madrasensis. S. gryphoides, M. casta and the gastropod Hymnaea sp. were recorded at Site III. It is significant to note that at Sites II and III, the molluscan fauna was represented only by a few species, while at Site I the number of species was more.

(iii) Epifauna on C. (C.) cingulata: During the course of observation, it was noted that C. (C.) cingulata was encrusted with the barnacle Balanus amphitrite and the oyster Saccostrea cucullata. Incidences of encrustation by minute algae and the presence of egg capsules of another gastropod Clithon oulaniensis were not uncommon. Percentage occurrence of barnacle/oyster infested specimens in the population is given in Table 6. It is of interest to note that oyster infested specimens were found only at Site I, while algal encrusted specimens were recorded from Site III. Generally, individuals above 15 mm size were only found to be with epiphytes and epifauna.

During the collection of live samples, dead shells of C. (C.) cingulata were also present in large quantities. Some of them were occupied with the hermit crab Clibanarius longitarsus. Monthwise estimated quantity of dead shells and number of hermit crab found in such shells are given in Table 7.

3.1.4 Discussion

The rainfall in 1982 was less and the salinity did not show much variation compared to 1983 when there

were severe floods and the topography of the entire estuary was altered making the river mouth straight and broad just as in 1977 (when there was unprecedented flood accompanied by a cyclonic storm). This helped in the penetration of sea water into the estuarine system and also in flushing, which was beneficial to the estuarine biotic community. Influence of monsoon on the estuarine system was well documented in the works of Jayaraman (1951), Ganapati and Murthy (1955), Krishnamurthy (1966) and Nair et al., (1983a).

The trend between the atmospheric temperature and sediment and surface water temperatures indicated the dependency of the latter two on the former. However, there were some variations in the surface water temperature during cooler months, possibly due to inflowing neritic warm water keeping the water temperature slightly higher than atmospheric and sediment temperatures. Such (tidal induced) temperature changes were noticed by Qasim and Gopinathan (1969) in Cochin Backwaters. Similarly, during summer, percolation through substratum keeps the substratum temperature closer to water temperature than to atmospheric temperature. Shallowness of the study sites might also be a reason for temperature variations, governed also by climatological conditions, as observed by William (1966). In general,

temperature is more dependent on the season and therefore on local climate. In tropical waters, in general, annual variations in temperature are limited, as is also the case at Porto Novo. Earlier workers (Jacob and Rangarajan, 1959; Dyer and Ramamoorthi, 1969; Vijayalakshimi, 1973; Rajendran, 1974; Chandran, 1982 and Sivakumar, 1982) have also recorded similar observations regarding temperature variations.

When there was low precipitation during the north-east monsoon period of 1982, the salinity remained steady at Site I, but was lowered upto 14‰ at Sites II and III. On the otherhand, the salinity dropped to much lower levels during the monsoon months of 1983 and early part of 1984 due to incessant rains at Porto Novo and sorrounding areas.

Tide induced salinity rhythem was reported by Vijayalakshimi (1973), who found an increase in salinity during high tide. Sivakumar (1982) stated that salinity variations were minimal during summer and nil in monsoon period during differing tides, but was more pronounced during the pre- and post-monsoon months. He stated that the presence of freshwater at the surface and the more dense sea water at bottom (the salinity wedge) may be the causative factor for this. The low saline condition from September 1983 to March 1984 was due to the prevention of the intrusion

of neritic waters into the estuary by the fast flowing flood waters.

Dissolved oxygen concentration was observed to be comparatively high during cooler months than in summer. Low temperature and less saline waters might influence the dissolution of more oxygen in the estuarine water as observed by Dehadrai (1970), Dwivedi et al. (1973) and Thangaraj et al. (1979) in Indian estuaries. Parulekar and Wagh (1975) observed that dissolved oxygen was not a limiting factor for the distribution of benthic fauna. Calder et al. (1977) observed that oxygen may not govern the distribution of benthic fauna in shallow estuaries where the flow is continuous. Consistently high oxygen content in the study sites can be attributed to the shallowness of the area as well as to the continuous flow of tidal waters.

Hydrogen-ion concentration of water did not vary much with seasons and was always alkaline in nature. However, comparatively low values were observed in the case of sediment samples at Site I during early part of the study, which might be due to settling of wastes washed away from the adjoining fish landing centre and subsequent decomposition. This condition did not continue for long and so high pH values were recorded from January 1983 onwards.

Organic carbon in the sediment could be derived from primary production in the estuary (autochthonous) and also from the terrestrial biota (allochthonous)(Nair et al., 1983a). In the present observations, organic carbon content varied from 3.1 to 17.3 mg/g which was similar to the values observed by Sivakumar et al. (1983) at three stations of the Vellar estuary, but less than the quantity recorded in Cochin Backwaters (Sankaranarayanan and Panampunnil, 1979). Generally, high values of organic carbon content found during summer and premonsoon periods might be due to alkaline conditions prevailing in the estuary, which accelerates the decomposition of plant residues deposited as peat in top layers of the substratum (Walsh, 1967). Organic carbon content was always more at Site II. Nair et al. (1983b) observed high carbon content in the substratum in the upper reaches and sheltered areas of the estuary. They also observed that the organic carbon content was high during the premonsoon than in summer. Damodaran and Sajan (1983) and Nair et al. (1983a) observed high organic carbon content in the clayey and silty substratum than in a sandy one. It is generally known that clayey substratum is capable of withholding more organic carbon than sandy particles. The shallow nature of the area, the very location in the upper

reaches and also the clayey condition of the substratum might all be attributed as reasons for high organic carbon content of the substratum at Site II than in other two sites.

Site III had high percentage of sandy particles and the texture was sandy, while at Site I, the substratum was sandy to clayey sand with predominance of sand particles. On the contrary, at Site II, the substratum was clayey sand during most of the months. Sheltered nature of this area might have offered congenial conditions for the settlement of clay particles in suspension in the discharge from the adjoining channel. However, during the flood season, this area also becomes more sandy because of washing away of fine particles of silt and clay. Constant tidal flow with high velocity might be the reason for a sandy substratum at Sites I and III. The latter, though situated in a more sheltered area away from the mouth, is influenced by tidal flow from the Vellar and the Coleroon river mouths, causing erosion of the clayey and silty particles in suspension.

Subramanian (1981) discussed in detail the diurnal and seasonal variations in the standing crop of phytoplankton in the Vellar estuary. The summer peak of phytoplankton was also observed by him. He attributed the phytoplankton abundance in summer to the reduced water exchange or tidal

variations. Reduction in numbers of phytoplan... s monsoon is due to low salinity whereas during premo... this is caused by grazing of zooplankton. Salinity depe... phytoplankton abundance has earlier been observed by Santhanam (1976) in the Vellar estuary. Comparatively low quantity of phytoplankton was observed at Site III in the present study which is also in accordance with the observations made by Santhanam (1976) and Ramadhas (1977).

Few numbers of zooplankton could only be observed during monsoon in both the years, due to low salinity. Though there was no substantial precipitation and flooding during 1982, there was still a decline in the number of zooplankton. Salinity dependent plankton abundance was observed by Madhupratap (1976) and Goswami and Selvakumar (1977). High zooplankton density of 1,47,300/m^3 was recorded in October 1983 which is comparable to earlier records of 1,38,333/m^3 in Lawson's Bay (Ganapati and Rao, 1958), but much less than 2,86,000/m^3, reported by Subbaraju and Krishnamurthy (1972) from the Vellar estuary.

Percentage of gastropod veligers in the zooplankton biomass was observed to be high during February-April, which appears to correspond with high breeding activity of snails in the estuary.

Presence of macrovegetation along the shore offers shelter for the snails besides providing them with food. By decomposition, they form high detrital food for bottom feeders. Often, the floating algae carry a number of organisms with the tidal flow and acts as a means of transportation. Site III was occupied by angiosperms, Site II contained mainly floating colonies of Enteromorpha sp., while Site I was matted with many algae, and limited quantity of angiosperms.

Molluscan faunal composition of the three different sites also showed dissimilarity with relatively few species at Sites III and II compared to more number of species occurring at Site I. The former two sites, located in upper reaches, were subjected to variations in salinity while the Site I was relative more stable. This excluded the high saline forms from Sites II and III. Salinity tolerant gastropods and bivalves only were distributed in these two sites. However, C. (C.) cingulata was dominant at all 3 sites, which shows its capacity to adapt to environmental changes.

To be in short:

1. The Vellar estuary is profoundly influenced by rainfall during northeast monsoon (October-December). Not only the

hydrographical conditions, but also the topography was affected by heavy flood water flow during this period.

2. Water and sediment temperatures follow closely the air temperature, depending on climatological conditions during monsoon and other seasons.

3. Salinity was dependent on the river water inflow and penetration of neritic waters. Water salinity was maximum during summer and premonsoon and low during monsoon in all three sampling sites.

4. Dissolved oxygen content was high during monsoon and postmonsoon and low in summer.

5. The pH of estuarine water as well as sediment was on the alkaline side.

6. The organic carbon content of the sediment was high in summer and premonsoon, but low at monsoon.

7. The texture of the substratum was sandy at Sites I and III, while it varied from clayey sand to sandy at Site II. This was because of sheltered location of the site.

8. Summer phytoplankton peak and the premonsoon zooplankton peak are characteristics of the Vellar estuary.

9. Macrovegetation composed mainly of angiosperms at Site III, of Enteromorpha sp. at Site II, but by many species of algae at Site I.

10. Molluscan fauna constituted mainly of C. (C.) cingulata at all three sites. Numerically more species were present at Site I than in other two sites.

11. Specimens of C. (C.) cingulata were infested with epizoic forms such as Balanus amphitrite and Saccostrea cucullata, and also by minute algae. Dead shells of the snail were occupied by the hermit crab Clibanarius sp.

3.2 TOLERANCE TESTS

3.2.1 Introduction

Estuarine molluscs are subjected to variations in water salinity and temperature (both diurnally and seasonally), ranges of pH, water currents and suspended maters. In the intertidal environs, they are also affected by desiccation and wave action. Tolerance of these extremities helps in colonising the area by a number of organisms and Cerithidea (Cerithideopsilla) cingulata is one such organism showing adaptability to such conditions and colonising intertidal region of the Vellar estuary. Hunter (1964) pointed out that the molluscan fauna in the estuarine environment is limited

to a few species (which can adapt to these conditions), but numerically abundant as individuals. The high density of the population of C. (C.) cingulata proves its adaptability to varying estuarine conditions. The present investigation was undertaken particularly to assess the tolerance of this species to salinity, temperature and exposure, the three important influencing factors in any intertidal environment.

Salinity is a major factor influencing the distribution of snails in the estuarine environment (Redeke, 1932; Segerstrale, 1951, '53; Gunter, 1956, '61; Kinne, 1963, '64). These snails distribute themselves over definite salinity ranges and seem to be quite sensitive to salinity differences near the lower range than to upper salinity limits (Gunter, 1956). Reduced permeability of body surface, active uptake of salts from external medium and production of hypo-osmotic urine are the mechanisms often employed by organisms which inhabit low salinity and freshwater environments for maintaining hyperosmotic body fluids in dilute medium (Vernberg and Vernberg, 1972). As mentioned earlier, C. (C.) cingulata is distributed in the marine, gradient, tidal and freshwater zones of the Vellar estuary, indicating adaptive nature of the snail to such ranges of salinity. Therefore, to determine the favourable salinity in which

greater activity is shown by this species, and the adverse salinity where the snails become inactive and struggle to survive, the present study was undertaken. Majority of studies on salinity tolerance of gastropods are on rocky shore forms (Gowanloch and Hayes, 1927; Broekhuysen, 1940; Arnold, 1957, '72; Berry, 1961; Balaparameswara Rao and Ganapati, 1972; Rosenberg and Rosenberg, 1973) and on sandy shore forms (Rajagopal, 1982). Similar studies on estuarine forms are scanty. Scott and Cass (1977) studied the response of C. californica to low salinities and its paleontological implications. Prabhakara Rao (1980) studied oxygen uptake of C. (C.) cingulata in different salinities and found that there was a gradual reduction in the uptake from 15 to 5‰ and no oxygen consumption at 0‰.

Another concern in the intertidal habitat is the effect of high or low water temperature. All animals could temporarily tolerate temperatures well in excess of those experienced on the shore and so the possibility of death under natural conditions is remote (Huntsman and Sparks, 1924). Evans (1948), Orr (1955), Gunter (1957), Hodgkin (1959), Fraenkel (1960), Kinne (1963) and Balaparameswara Rao and Ganapati (1972), have studied the effects of high water temperature on intertidal gastropods. Occasionally

intertidal communities are faced with exceptional climatic or tidal conditions wherein they are exposed directly to atmospheric temperature and incineration by exposure. In shallow areas with less flushing, the water temperature tends to increase during midsummer affecting adversely its inhabitants. Tolerance of C. (C.) cingulata to such increased water temperature has been studied presently.

Desiccation during the period of exposure is another important cause of mortality among intertidal community, and its capacity to control or withstand water-loss is a major factor deciding the zonation of littoral species (Gowanloch and Hayes, 1927; Brockhuysen, 1940; Stephenson, 1942; Allanson, 1958; Southward, 1958; Brown, 1960; Segal and Dehnel, 1962; Kensler, 1967; Davies, 1969; Balaparameswara Rao and Ganapati, 1972; Prabhakara Rao, 1980). Desiccation for a limited period may be tolerated by intertidal animals, but, prolonged exposure will prove to be fatal. Therefore, the tolerance of C. (C.) cingulata to desiccation has also been studied presently.

3.2.2 Material and methods

Specimens of C. (C.) cingulata collected from the Vellar estuary were utilised for this study. For salinity

tolerance tests, specimens from three sites (referred earlier) were collected and employed separately for different experiments. However, for the temperature and desiccation studies, specimens collected from only one site were used.

All the experiments were carried out during August-September 1982. During the period of collection, the salinity was 35‰ in Site I and II and 30‰ in Site III. The response of C. (C.) cingulata to water of different salinities was investigated by using filtered river mouth water of 35±0.5‰ salinity, diluted to steps of 5‰ with distilled water. Totally 8 different salinity concentrations were considered from 0 to 35‰. Since, salinity in all the three sites was between 30 and 35‰ at the time of collection, the estuarine water having 35‰ salinity was used for recording maximum response. Activities in other salinities were scaled in proportion to this following Arnold (1972). The response of the snail and the score assigned for such activities are given in Table 8. The snails were kept in glass aquaria of 2 litre capacity filled with 1 litre of water of appropriate dilutions. This provision of space was necessitated because of the habit of the animal to move above the water level. Ten animals were experimented in each salinity and the mean was used for further analysis.

Before transferring to experimental salinities, the snails were kept in the normal estuarine water for 48 hours for acclimatisation.

Response of C. (C.) cingulata to changes in salinity was studied by experimenting with snails of different size groups to various salinities and noting their activity after one hour. For this, specimens from all the three sites were grouped into 1-9 mm, 10-19 mm, 20-29 mm and 30-39 mm separately. The snails above 30 mm size were absent in Site I and II, while specimens below 10 mm were not encountered in Site III.

Effect of exposure to low salinity for a prolonged period was studied by keeping the snails for 30 days in various salinities. Activity of the snails and mortality, if any, was noted daily at 09:00 hours and the water was changed soon after.

Observations were also made on the time of recovery of the snails exposed to adverse salinity. This was done for the first 10 days, by returning the snails from such water salinity to the water with an ambient salinity of 35‰. The snail was considered as dead when it did not respond to tactile stimuli and failed to recover even 24 hours after its return to water of ambient salinity. Salinity estimations

were made with argentimetric titration as mentioned earlier.

Tolerance of C. (C.) cingulata to gradually rising water temperature was carried out following the method adapted by Evans (1948) by increasing the temperature by 1°C every five minutes. From an ambient temperature of 30°C, the raise was upto 50°C. Totally 100 snails were subjected to this experiment, keeping them in a 2 litre trough, filled with 1 litre of water. The set up was heated taking care to raise the temperature by 1°C every five minutes.

Behaviour of the snail to water temperature variations was recorded by employing the method of Fraenkel(1960). Sets of 10 snails were kept in glass troughs having 500 ml of estuarine water of ambient salinity with temperature of 32, 34, 36, 38, 40, 42, 44, 46, 48 and 50°C. After exposure for 1 hour, the animals were brought to room temperature to note down those snails which recovered.

Effects of desiccation on C. (C.) cingulata were studied following the procedure of Davies (1969). After weighing, specimens were kept in 50 ml beakers and placed in a desiccator containing anhydrous $CaCl_2$ as moisture absorbant. The specimens were weighed again at the end of the experiment and the weight lost was considered as equivalent to water-loss of the snails. Fifty snails were used for each experiment.

Following were the terminologies used to describe the results of the experiment:

1. Water-loss in percentage:

$$\frac{\text{Actual weight-loss (in mg)}}{\text{Total body weight (in mg)}} \times 100$$

2. Percentage of water-loss:

$$\frac{\text{Water-loss in each day}}{\text{Water-loss during whole period of study}} \times 100$$

3. Net water-loss: Percentage water-loss on a particular day - percentage water-loss on the previous day.

4. Water-loss per unit mg weight:

$$\frac{\text{Actual weight loss (in mg)}}{\text{Total body weight (in mg)}}$$

Total body weight = weight of shell and soft parts. All the experiments were repeated atleast four times and the average was taken.

3.2.3 Results

(a) Tolerance to low salinity:

Responses of different size groups of C. (C.) cingulata from Sites I, II and III to changes in salinity are given in Fig.33. They showed no activity in the

salinity range of 0 to 10‰, poor activity in water of 15 to 20‰, moderate activity in 25‰ and were most active in water of 30 to 35‰.

The results of the experiment to study the mortality rate and daily activity under various salinity conditions over a prolonged period showed variations among snails from three sites (Figures 34, 35 and 36 respectively). Activity was moderate to high in water of 25 to 35‰ salinity from the beginning in all the cases. In water salinities of 10 to 20‰, there was a gradual acclimation and snails became active after a few days. In water of 5‰ salinity, the snails from Site I showed very poor activity or were inactive from the beginning, leading to 100% mortality by the 26th day. Snails from Site II showed normal activity from 5th day onwards and no mortality could be observed till the end of the experiment. In the case of snails from Site III, while 40% were dead, others showed normal activity after a period of acclimation. In freshwater conditions, C. (C.) cingulata from all the three sites did not show any activity throughout the period of exposure and 100% mortality took place by the 13th, 24th, and 29th day among snails from Site I, II and III respectively.

The experiment on the time of recovery from adverse

salinity (in the present observation 0‰) to ambient salinity of 35‰ indicated that the time taken for such recovery increased with more number of days of exposure (Table 9). The reaction of snails, when returned to normal salinity, was to protrude the head and exhibit signs of relaxation (activity scale 1). No movement was noticed immediately, but only after sometime. The above activity was noticed within 2 to 3 minutes on the first three days, but delayed to 50 to 65 minutes after 10 days exposure.

(b) Tolerance to increased water temperature:

Behaviour of C. (C.) cingulata in gradually increasing water temperature is summarised in Table 10. Up to 38°C, the snail showed normal activity and the recovery was quick when returned to room temperature. At 41°C the snail showed vigrous movements, but at 44°C the avtivity slowed down. At 46°C and 47°C, the animal moved its head, but could not move the shell indicating lack of muscular coordination. At 48° and 49°C, the head was withdrawn into the shell and some mortality occurred. Revival time also increased in these two temperatures. At 50°C, the snail withdrew completely into its shell and the mortality was total.

On continuous exposure to increased temperature for one hour, C. (C.) cingulata tolerated well upto 46°C, but showed mortality from 48°C onwards, which was total at 50°C (Table 11).

(c) Tolerance to exposure:

The immediate response of C. (C.) cingulata to aerial exposure is to withdraw its head and foot into the shell and close the aperture with operculum and to continue to remain in such condition till it was returned to normal conditions.

Snails of 13.2 to 28.5 mm shell size (total weight ranging from 210 to 1780 mg) were used to study the rate of water-loss. After initial weighing, the snails were reweighed after 6, 12 and 24 hours and thereafter at intervals of 24 hours for 12 days by which time total mortality took place.

The water-loss in percentage recorded on successive days of exposure is given in Fig.37. The water-loss was very high initially, but was steady at later stages. The high initial rate could be due to evaporation of adhering and shell-water (Davies, 1969). Due to this reason, in subsequent analysis, the water-loss for the first 12 hours was not considered.

Surviving animals on successive days of exposure (Fig.38) indicated that upto 4th day, 100% of the snails survived; 50% survived until 7th day, but all of them were dead by 12th day. When mortality and water-loss in percentage were correlated (Fig.39), it was observed that upto a water-loss of 10%, there was no mortality. But at 12.8%, there was 15% mortality and at 14.3%, the mortality was total.

When percentage of water-loss on successive days was plotted, an ascending trend was observed. But net water-loss on each day showed an inverse trend (Fig.40).

In order to examine the relationship between the size of the snail and water-loss, actual weight loss in mg and water-loss in percentage were plotted against shell length. The former showed increasing trend, while the latter, a descending trend (Fig.41).

Logarithmic values of actual weight-loss in mg were plotted against the total weight of individuals (Fig.42.A), which indicated a linear relationship. This could be represented by using the regression equation,

$$\log y = a+b\ w$$

where y is the weight-loss in mg, w the total weight in mg and a,b the constants. The values obtained are:

$$\log y = -1.2002 + \log w\ 0.9715$$

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The above relationship is highly significant at 0.1% confidence limit, since the correlation coefficient 'r' was equivalent to 0.8583. However, the water-loss per unit mg weight in snails of lower to higher body weight showed a negative relationship (Fig.42.B). The equation applied was

$$\log \frac{Y}{W} = a + \log w\ (b - 1)$$

where $\frac{Y}{W}$ is water-loss for unit mg, w is the body weight in mg and a,b constants. The values obtained are:

$$\log \frac{Y}{W} = -0.2675 + \log w\ -0.3584$$

The above relationship is also highly significant at 0.1% level confidence limit, the 'r' being 0.6984. The above relationships are comparable with those obtained for Cellana radiata by Balaparameswara Rao and Ganapati (1972).

Observations showed that in snails which were subjected to desiccation and then returned to water of ambient salinity and temperature, their recovery was marked and rapid. However, the time taken for recovery differed according to exposure and percentage of water-loss. The results are given in Fig.43.

3.2.4 Discussion

Arnold (1972) recorded maximum activity among molluscs of different species found in their preferred ranges of salinity. From the present study, it can be stated that C. (C.) cingulata shows maximum activity in water of 30 to 35‰ salinity, which appear to be its optimal or preferred level. From 5 to 20‰, the animal acclimatised gradually and only moderate activity could be noted, indicating its tolerance limit. On the otherhand, the snail was either inactive or showed poor activity at and below 5‰, where mortality also occurred. Ja Berger (1978) observed that littorinids seal the mantle at considerable deviation of salinity from the optimal. They showed capacity adaptation such as inhibition of respiration within the tolerable limit, but irreversible altercation of cells took place and the animal died subsequently on constant exposure to resistance zone (or untolerable lower salinity). Prabhakara Rao (1980) observed in C. (C.) cingulata that the oxygen uptake was steady upto 20‰, but declined sharply from 15‰ onwards and there was no oxygen uptake at all, at 0‰. Arnold (1972) suggested that low activity in the animal would lead to mortality, since such activity cannot ensure vital functions such as collection of food and resistance to other environmental factors.

Therefore, the salinity in which the minimum activity (scale 2 or less) is maintained, is adverse to the snails. Exposures to water salinity of 5‰ and below for longer periods appear to be lethal to C. (C.) cingulata. This tolerance capability explains the wide distribution of the species in the Vellar estuary. Scott and Cass (1977) and Race (1981) also observed wide range of salinity tolerance in a related species, C. californica.

There appears to be no difference in tolerance to salinity between large and small snails nor among snails from the three localities. Slight differences observed between them may be due to variations in physiological responses as needed for each locality.

Tolerance of C. (C.) cingulata to increased water temperature was similar to the observations of Balaparameswara Rao and Ganapati (1972) on the limpet C. radiata. When compared to the lethal limit of C. radiata, C. (C.) cingulata appears to be more tolerant.

The impacts of desiccation have been found to vary with humidity, temperature, duration and degree of exposure and wind velocity (Pechenik, 1978). Tolerance of C. (C.) cingulata to desiccation was found to be almost that of C. californica, which tolerates exposure even upto 15 days

without any mortality (Race, 1981). Resistance to desiccation was attributed to location of the species in a shore by Davies (1969). He experimentally clarified that Patella sp. from HWM was more tolerant to desiccation than the organisms nearer to LWM. Balaparameswara Rao and Ganapati (1972) also observed a similar behaviour among individuals of the limpet C. radiata. Since, C. (C.) cingulata is not found near the high water mark (HWM), but migrates along with the tide, such high tolerance seems to be absent.

In gastropods, unlike in bivalves, proportionately small areas of soft parts are exposed, even when the snail is crawling; water-loss is further reduced by the adherence of a snail to rock or other surface (Yonge, 1949; Brown, 1960) or by the closure of the shell with the operculum. The operculum has generally been considered to be of importance in reducing water-loss, but not inevitably so (Gibson, 1970). Mantle-water also plays an important role in the snails' tolerance to desiccation. C. (C.) cingulata reacts to desiccation by moving towards water front along with lowering tide or by attaching itself to the algal fronds or algal patches. Since snails of smaller size lose comparatively high percentage of water than the larger ones, their distribution is very much restricted to the low level

(LWM), or in association with the algal mats.

Exposure to a limited period of 12 hours during the diurnal tidal cycle is said to be tolerated by shell closure or by reduced metabolic activity (Davies, 1969). Those organisms located near the high level of spring tide (HHWM) during the new and full moon phases will be exposed to severe desiccation. In such cases, the immersion will be possible only during next spring hightide after a fortnight. These organisms will face greater mortality because of prolonged exposure, leading to heavy water-loss due to high temperature. These organisms have to cope with such contingencies either by moving away from that site or by adjusting their physiological and metabolic activities until favourable conditions return.

The salient features of the present study can be summarised as follows:

1. C. (C.) cingulata, shows normal activity in water of 25 to 30‰ salinity, moderate activity in water of 20 and 15‰ salinity and very low activity in 10, 5 and 0‰ salinity.
2. There is no difference in the above between different size groups and populations from different sampling sites.
3. C. (C.) cingulata acclimatises to water of 5‰ salinity, but below this, the snail is affected adversely.

4. The time for recovery at ambient conditions was quick during early stages, but was found to be more after a few days of exposure.

5. C. (C.) cingulata shows normal activity upto 42°C water temperature but was killed at 50°C. On continuous exposure for 1 hour, it died at a water temperature of 48°C and above.

6. Exposure for 12 days resulted in a water-loss in percentage of 14.3%, which led to 100% mortality.

7. Water-loss in percentage was more during the first 12 hours, but steadied after 48 hours.

8. Percentage of water-loss increased with more days of exposure, but net water-loss did not.

9. Actual weight-loss in mg increased with an increase in size, but water-loss in percentage showed decreasing trend.

10. Actual weight loss in mg increased with total body weight and log values showed a linear relationship; the equation was: $\log y = -1.2002 + \log w\ 0.9715$

11. Water-loss per unit mg weight showed a negative relationship; the equation was:

$$\log \frac{Y}{W} = -0.2676 + \log w\ -0.3584$$

12. Time for recovery from the effects of desiccation was quick during the first few days, but slowed down with greater exposure time.

13. Closure of aperture by operculum and reduced metabolic activity appear to be mechanisms adapted by this snail to conditions of adversity.

3.3 DISTRIBUTION PATTERN OF THE POPULATION

3.3.1 Introduction

A general feature of estuarine fauna is the occurrence of relatively few species but these few species are numerically abundant as individuals (Hunter, 1964). Molluscs of the estuarine region follow this generalisation as a rule and often the density reaches the "pure culture level" in the case of the mud snail Hydrobia ulvae (Nicol, 1935; Rees, 1940; Spooner and Moore, 1940; Hunter and Hunter, 1962; Sanders et al., 1962; Green, 1968). Similar observations have been made in the case of Assiminea bifasciata and Melampus serliaratum (Brown, 1971), H. totteni (Wells, 1978) and C. californica (Race, 1981).

C. (C.) cingulata is a widely distributed species in the intertidal area of the Vellar estuary. It is a hardy snail and has been reported from brackishwater to hypersaline

fish ponds with a salinity range of 15 - 45‰ (Panikkar and Aiyer, 1939; Van Bentham Jutting, 1956; Chuang, 1961). It has also been observed to live in almost liquid mud in inland creeks, river banks and along freshwater seepage gulleys and on tidal sand flats (Vohra, 1970).

Studies on the distribution and behaviour of estuarine molluscs are limited to Hydrobia spp. (Newell, 1962; Muus, 1967; Anderson, 1971; Fenchel, 1975a,b; Little and Nix, 1976; Wells, 1978), Nassarius obsoletus (Crisp, 1969; Pechenik, 1978; Race, 1981), Terebralia spp. (Wells, 1980) and C. californica (Race, 1981). Distribution, zonation and habits of C. (C.) cingulata in the Krishna estuary was studied by Balaparameswara Rao and Sukumar (1982) and the population structure from the sandy beaches of Singapore was observed by Vohra (1970). However, not much information is available on the distribution patterns of C. (C.) cingulata over short and longer durations. Therefore, a detailed investigation was carried out during the two year period from September 1982 to August 1984 and the results are presented here.

3.3.2 Material and methods

Preliminary investigations showed C. (C.) cingulata from river mouth to 8 km upstream in the Vellar estuary as well as in channels connecting the Coleroon estuary. Therefore, to study the distribution pattern, the entire estuary was surveyed locating 10 stations randomly on either bank (Fig.44). At each station 3 samples were collected at 5 tidal levels, viz., HWM, MWM, LWM, 5 m above HWM and 5 m below LWM. Samples were collected using a quadrat of 30x30 cm size. Randomisation was achieved by throwing the quadrat after rotating a number of times with eyes shut to disorientate the collector (Vohra, 1970). The entire sediment sample with organisms upto a depth of 10 cm within the quadrat was removed and pushed through a sieve of mesh size 0.85 mm (B.S.18) to collect the snails. This was repeated thrice and the samples were then pooled for further study. The snails were weighed, counted and the total was calculated for m^2.

To study the variations in population size during different months, samples were collected every month from Sites I, II and III. Size composition of the population was studied by measuring shell size to the nearest 0.1 mm with a Vernier calipre, in a subsample (25% of the total quantity).

For studying the movement of snails, an intertidal area opposite the Biological station, where the tidal gradient was 0.42 m, was selected. The total distance between LWM and HWM was 12 m and this was divided into 4 transects of 3 x 3 m squares. Groups of snails numbering 300 were painted with enamel paint of red, green, yellow and white colours and each group then was released in different transects (I transect - green; II - red; III - yellow and IV - white). The experiment started at 06:30 hours in the morning of 6.8.1982 and subsequent sampling was done at 10:30 hours, 14:30 hours, 18:30 hours and on the next day morning at 06:30 hours covering 24 hrs and two tidal amplitudes. After counting the snails, they were returned to the same spot from where they were collected. The experiment was repeated on subsequent 2 days and the data were pooled for study.

1200 snails were painted white and released into a marked area of 5 m^2 in the estuary opposite the Biological Station on 28.1.'83. Subsequent counting of the specimens was carried out daily during low tide for the next 5 days and then once in 5 days for a period of one month.

3.3.3 Results

(a) Distribution in the estuary:

Based on the survey conducted, Station 2 was the extreme limit of distribution of C. (C.) cingulata in the upper reaches of the Vellar estuary. Abundance was more in Stations 3, 6 and 10, moderate in 2, 5, 7, 8 and 9, but absent in 4 where a channel discharges freshwater into the estuary (Table 12).

When the distribution of C. (C.) cingulata at different tide level was compared (Fig.45), it was observed that the snail occurred more densely in MWM than at LWM. But over the MWM, its distribution was scarce upto HWM and totally absent beyond that level. Similarly no live animals were observed at 5 m below LWM.

Of the ten factors considered to find out their influence on the distribution of C. (C.) cingulata, sandy substratum, salinity, presence of algae, organic carbon content of the sediment, pH of the water and sediment and dissolved oxygen content were all found to have a synergestic effect. C. (C.) cingulata, preferred sandy substratum, high saline water, algal mat, high organic matter, an alkaline pH and an optimal quantity of dissolved oxygen. Increase in temperature, silt and clay particles seem to affect the distribution in a very limited way.

(b) Population fluctuations:

Density of population of C. (C.) cingulata at Sites I, II and III are shown in Figs. 46, 47 and 48, respectively. Population density by weight and by numbers per m^2, and the length composition were studied from all three sites.

Site I:

High density of C. (C.) cingulata was recorded from this Site (Fig.49). A maximum of 12,500 snails/m^2 (873 g) was recorded in September 1982. Number of snails decreased during summer (April-June) and increased in August, September (premonsoon).

Length composition ranged from a mean shell length of 7.5 mm (September 1982) to 14.2 mm (May 1984)(Fig.50). The mean shell length increased from September till May/June and decreased during June-August when new recruits were added to the population.

Site II:

Population density at this site also showed a similar trend to that of Site I (Fig.51). The concentration of snails observed was in January 1983 (7298/m^2; 762 g) and the lowest was in March 1984 (620/m^2; 465 g). The density was in general less during the post-monsoon (January-March)

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and summer, but increased when a large number of , made their appearance during premonsoon (July-September,

The mean shell size in the population ranged from 7.9 mm (June/July 1984) to 19.7 mm (April 1984)(Fig.52). The mean shell length showed an increase from September to May, but there was a fall during June-August, when smaller sized juveniles altered the length composition.

Site III:

Population density (Fig.53) both by weight and numbers was less in this area. A density of 432 snails/m^2 (628 g) could be observed in August 1983 and a low concentration during December in both the years. No wide fluctuations could be noticed and the population was mostly the same throughout the period of observation.

Length composition study (Fig.54) showed that the population composed mainly of large sized animals and naturally, the mean shell length was higher than in the other two sites. The largest specimen of C. (C.) cingulata (shell size 39.4 mm) was collected from this site. The mean shell length fluctuated between 24.8 and 27.3 mm; the former was recorded in July 1984 and the latter during March 1984. Specimens less than 12 mm in shell size were not encountered in this site, indicating that there was no

settlement of spats after breeding. Therefore, the population was wholly supported by migrants from adjoining areas, is more than obvious.

(c) Movement of the population:

Tidal movement:

Number of marked specimens released in transects and recovered at 06:30 hours, 10:30 hours, 14:30 hours, 18:30 hours and 06:30 hours on subsequent day are given in Table 13. The tide was rising in the morning and highest level was reached by noon. The animals collected were less because of limitation for sampling, in knee deep water. At 14:30 hours and 18:30 hours and again in the next mornings, the tidal level was low when maximum collection could be made. A perusal of the table indicates that there was little movement during the first four hours, when tide was rising, but movement was observed to be more once the tide started receding. Maximum movement was observed from transect 3, either upway to transect 2 or downward to transect 4.

C. (C.) cingulata moved with tide in all directions, and this resulted in a loss in many numbers of specimens from transects. It is also evident from the table that these snails are capable of moving upto 3 m distance during a tidal cycle.

Dispersal over longer period:

Recovery of marked snails from the date of release upto one month is given in Fig.55. 21% of the snails released moved away from the transect in one day and 50% by the fifth day. More addition was observed in the next five days, but they also moved away so that only 25% were left in the transect at the end of 30 days. This indicates that there is no homing instinct in the case of C. (C.) cingulata.

3.3.4 Discussion

Distribution of C. (C.) cingulata in the Vellar estuary is similar to Nizam Patnam canal in the Krishna estuary in that its distribution is limited to the upper reaches, where tidal influence could be noticed (Balaparameswara Rao and Sukumar, 1982). In the Nizam Patnam Canal, it is only 3 km from the river mouth, whereas in the Vellar estuary it is upto 8 km from the river mouth.

Depth influenced the distribution of C. (C.) cingulata to a great extent. It is scarce at HWM and totally absent above that level. Similarly no snails were found below LWM. This conforms with the observations of Balaparameswara Rao and Sukumar (1982) for this species,

at Nizam Patnam Canal of Krishna estuary. Wells (1978) showed depth as the main environmental variable affecting the density of the population of H. totteni. Anderson (1971) also observed a similar phenomenon in the distribution of H. ulvae. The absence of specimens in the upper intertidal region can be attributed as due to temperature and desiccation, while the lack of C. (C.) cingulata below LWM can be attributed to the factors such as predation and competition, which are more important in controlling the lower distribution limit of marine intertidal species (Connell, 1961, '70).

Presence of algal matter also appears to be a factor of importance in the distribution of C. (C.) cingulata. It was observed in the laboratory that whenever Enteromorpha compressa was introduced, the snails were observed to aggregate around this alga. Utilisation of algal patches for shelter from wave action and aerial exposure have been reported to be common among intertidal molluscs such as cerithiids (Ayal and Safriel, 1980). Very often, the algal mat of Enteromorpha was observed to carry a number of juveniles and even adults of C. (C.) cingulata, which may use the algae for shelter mainly and also as food. They are washed both with the rising and receding tides and were often stranded at high level, when wind induced wave action

was strong. This appears to be passive which can carry the animal to much longer distance than the actual coverage by locomotion (of the snail). Unless the snail is able to move away from algae with receding tide, it will get stranded with algae and will face severe heat and desiccation. Such incidences were seldom observed during the course of observation. In the case of stranded algae, an examination revealed that they were devoid of snails, indicating that the snails might have moved away. The algal mat can provide shelter from desiccation at least for a few days and the stranded snails were often found at the bottom of the algae burrowed in the wet substratum. However, prolonged exposure will naturally leave both the algae and its inhabitants dead. The habit of burying under the mat of Salicornia was observed by Race (1981) in the case of C. californica.

Salinity is another important factor influencing the distribution of C(C)cingulata in the estuarine environment. Redeke (1932) found the chloride content of water, to be the most important in governing the distribution of estuarine species and this view was supported by the works of Segerstrale (1951,'53) and Gunter (1956,'61). Newell (1964) found the distribution of H. ulvae in British estuary controlled by salinity to a large extent. Fenchel (1975a)

explained that salinity was a major factor in determining the distribution pattern of three species of Hydrobia in Limpjord in Denmark. Absence of C. (C.) cingulata beyond 8 km in the upper reaches of the estuary can be attributed to less saline and more freshwater conditions at the extreme upper reaches of the estuary.

The nature of the sediment is another factor of importance in the distribution of C. (C.) cingulata. The snail feeds on detrital matter from sediment and probably on microorganisms found in the sediment. Thus sediment grain size is important in determining the distribution of this species. Balaparameswara Rao and Sukumar (1980) showed that the concentration of the snail increased with increasing percentage of sand mixed with mud, but poor in pure mud or in pure sand. Newell (1965) found H. ulvae to be abundant in finer sediments and rare in coarse sediments. He suggested that the density of microorganisms, on which H. ulvae feeds was more in finer sediment. Franz (1976) was also of the opinion that the association of molluscs with very fine sand is connected with deposit feeding. Benthic animals, which feed on very small particles of detritus, occur most abundantly in areas where the particles (silt, clay, organic material and bacteria) are most abundant.

Wells (1978) observed that sediment size is an important factor in the distribution of H. totteni. Wells (1980) also emphasized the importance of the sediment size in the distribution of two potamidids, T. sulcata and T. palustris. The former was abundant in comparatively coarse sediment, while the latter preferred finer sediment. C. (C.) cingulata prefers a sandy-silt substratum mixed with clay than pure sand or hard clay. Absence of this species at Station 1 may be due to pure sandy nature of substratum while its absence at Station 4 can be attributed to the pure clayey soil.

Crisp (1969) observed that N. obsoletus preferred a substratum with more organic material. Pennak (1951) stated that although the organic detritus undoubtedly formed the most important food element in the intertidal ecosystem, it seldom appeared to be a limiting factor. Balaparameswara Rao and Sukumar (1981) were of the opinion that the organic carbon content as well as the sediment particle size might influence the distribution of C. (C.) cingulata. In the present study, the organic carbon content of the substratum seems to serve as one of the factors, influencing the distribution of C. (C.) cingulata.

Dissolved oxygen content, pH of the substratum as well as that of water were also observed to influence

the distribution of C. (C.) cingulata in the present study. Wells (1980) has also reported that T. palustris and T. sulcata avoided roots of Rhizhophora where the pH was always lower (on the acid side).

Fluctuations in the density of populations of Cerithidea spp., during different seasons, appear to be common. Race (1981) attributed the variations in density of C. californica, during different months, to migration by the snail to favourable sites, when adverse conditions prevailed. The same appears to be true regarding the variations in the Vellar estuarine populations of C. (C.) cingulata.

An increase in mean shell lengths of C. (C.) cingulata can be attributed to growth, and the fall could be either due to settling of new individuals, or to the mortality among older individuals as observed by Vohra (1970).

Dissimilarity in size composition at different stations within the estuary bears similarity to that of C. californica, as observed by Race (1981). She stated that differences may be due to differential rates of growth or longivity. Vohra (1970) concluded that the smaller size of C. (C.) cingulata on the sandy beaches of Singapore was probably due to poor availability of food compared to other

places where the species attained large size. The differential sizes of this species in the Vellar estuary may be due to any of the three reasons, viz., differential growth rate, longivity or poor food availability during seasons of adversity.

Movement with tide is known among the intertidal gastropods. Manmadha Rao (1977) observed that Clypeomorus sp. moved to a distance of 34 to 45 cm during 24 hours. Snails at the MWH were observed to cover more distance than those at HWL. Race (1981) observed that C. californica covered upto 10-12 m per day. Tide induced movement is more pronounced in C. decollata which climbed the mangrove trees during high tide and reached the ground during low tide (Macnae, 1963; Brown, 1971; Berry, 1972; Cockcroft and Forbes, 1981b).

Populations of C. (C.) cingulata move as a whole towards the water front during the receding tide, but moved up the beach with raising tide. The movement may either be straight or diagonal. Balaparameswara Rao and Sukumar (1982) observed similar behaviour in this species. When these snails could not cope with the rising tide they burrowed into the substratum. The sculpture of the shell of C. (C.) cingulata appears to aid in burrowing, like a ratchet, by holding the

shell firmly to the substratum while the snail is inserting its foot into the sediment (Phillip, 1983).

In the case of littoral animals, wetting by the incoming tides (Berry, 1963,'72; Southward and Crisp, 1965; Zann, 1973), acoustic shock caused by surf (Chandrasekharan, 1965), tidal hydrostatic pressure changes (Moulton, 1962; Morgan et al., 1964) and the rise and fall of water level (Underwood, 1972a,b) were proposed as possible stimuli inducing rhythmic activity in intertidal organism. Cockfort and Forbes (1981b) suggested the possibility of a change in humidity at the substrate - air interface, associated with a change in water table height, as causes for the initiation of movement in C. decollata, because the movement can take place even in the absence of contact with water. Being confined to the intertidal area, movement in C. (C.) cingulata appears to be stimulated by wetting through incoming tide, acoustic shock and by tidal hydrostatic pressure changes.

Migration for feeding during the receding tide (Brown, 1971), and ascending with tide as predator evading mechanism (Cockcrofts and Forbes, 1981b) are known. Berry (1972) pointed out that the ascent of C. (C.) obtusa and C. (C.) cingulata was to avoid complete immersion since they were lung bearing. But C. (C.) cingulata remains

alive for days together under submersion and therefore the problem of drowning is apparently remote. Predation by crabs appeared to be the reason for the ascending of Littorina irorata (Hamilton, 1976) and C. decollata (Cockcroft and Forbes, 1981b). This may probably be the factor for the ascending of C. (C.) cingulata, during the rising tide. This remains to be verified and confirmed.

Movements of snails over a long period indicated slow, but steady dispersal. This may be by active crawling or by passive dispersal through floating algal mats. Though there was considerable movement upto 3 m per tidal cycle, many of them stayed in the same location as evidenced by the presence of 80% of the individuals within a transect of 5 m^2, even after 24 hours. Nearly 25% of them were found in the transect even after 30 days and a few of them in the nearby environs until 6 months (vide the section on age and growth). Slow dispersal as observed in the case of C. (C.) cingulata has also been the case in C. californica, where some specimens were found, in the original locality of release, even after two years (Race, 1981).

Dispersal over a longer period was attributed to a physiological rhythm involving breeding and to locate a suitable site to overcome adverse conditions during monsoon.

Movement of larger size groups of C. (C.) cingulata towards upshore during February-June was also observed by Vohra (1970) who attributed it to breeding activity.

The findings of the present study can be summarised as follows:

1. C. (C.) cingulata occurs more densely in the MWM moderately between HWM and LWM, poorly between HWM and MWM, but absent above HWM and below LWM.
2. Besides depth, other environmental parameters like presence of algae, salinity, sandy substratum, organic carbon content of the substratum, dissolved oxygen content and pH of water and sediment were all found to influence the distribution of C. (C.) cingulata.
3. Dense population of C. (C.) cingulata was observed in the river mouth than in any other area.
4. Fluctuations in population density of this species appear to be the rule in the Vellar estuarine environment.
5. Mean shell length of the population of this species increased during the period of growth but registered a decrease at the time of recruitment of new stock.
6. C. (C.) cingulata moved with the tides and a coverage of 3 m per tidal cycle has been observed to be common.
7. 21% of the marked snails moved within 24 hours from the

site of release, 50% by fifth day and only 25% remained after 30 days.

8. Diurnal tidal movement can be attributed to feeding cycles.

9. Dispersal over long term may be to tide over a period of adversity or congregation for reproductive activities.

Table 1. Sediment composition (in percentage) and nature of substratum at site I.

Month	Sand	Clay	Silt	Nature of substratum
September 1982	92.52	7.08	0.40	Sandy
October	91.73	7.12	1.15	Sandy
November	89.45	5.79	4.76	Sandy
December	85.94	13.08	0.98	Sandy
January 1983	83.75	14.89	1.36	Sandy
February	74.10	25.35	0.55	Clayey sand
March	79.87	18.50	1.63	Sandy
April	81.43	18.37	0.20	Sandy
May	74.42	24.52	1.06	Clayey sand
June	75.77	23.09	1.14	Sandy
July	95.17	4.50	0.33	Sandy
August	87.29	11.41	1.30	Sandy
September	92.03	7.05	0.92	Sandy
October	97.27	2.63	0.10	Sandy
November	89.65	7.06	3.29	Sandy
December	91.43	4.57	4.00	Sandy
January 1984	92.20	4.87	2.93	Sandy
February	75.67	23.19	1.14	Sandy
March	87.93	9.06	3.01	Sandy
April	82.36	3.27	14.37	Sandy
May	86.87	11.98	1.15	Sandy
June	71.43	26.09	2.48	Clayey sandy
July	83.14	15.36	1.50	Sandy
August	83.06	16.04	0.90	Sandy

Table 2. Sediment composition (in percentage) and nature of substratum at site II.

Month	Sand	Clay	Silt	Nature of substratum
September 1982	72.39	26.86	0.75	Clayey sand
October	67.31	30.60	2.09	Clayey sand
November	74.09	21.42	4.49	Clayey sand
December	73.51	24.55	1.94	Clayey sand
January 1983	74.11	23.16	2.73	Clayey sand
February	66.35	30.55	3.10	Clayey sand
March	66.73	30.73	2.54	Clayey sand
April	64.26	30.32	5.42	Clayey sand
May	57.22	41.33	1.45	Clayey sand
June	32.35	62.73	4.92	Sandy clay
July	63.43	34.08	2.49	Clayey sand
August	76.01	22.95	1.04	Sandy
September	57.49	37.95	4.56	Clayey sand
October	62.32	23.56	14.12	Clayey sand
November	58.86	33.39	7.75	Clayey sand
December	83.46	14.90	1.64	Sandy
January 1984	72.62	23.98	3.40	Clayey sand
February	68.49	28.34	3.17	Clayey sand
March	75.93	22.44	1.63	Sandy
April	85.92	13.18	0.90	Sandy
May	74.11	23.16	2.73	Clayey sand
June	61.99	30.57	7.44	Clayey sand
July	68.40	29.14	2.46	Clayey sand
August	59.86	36.13	4.01	Clayey sand

Table 3. Sediment composition (in percentage) and nature of substratum at site III.

Month	Sand	Clay	Silt	Nature of substratum
September 1982	91.37	2.43	6.20	Sandy
October	87.55	8.10	4.35	Sandy
November	86.40	9.40	4.20	Sandy
December	90.45	6.80	2.75	Sandy
January 1983	78.40	18.35	3.25	Sandy
February	85.31	12.59	2.10	Sandy
March	89.45	9.47	1.08	Sandy
April	87.15	12.45	0.40	Sandy
May	78.20	20.60	1.20	Sandy
June	85.45	13.57	0.98	Sandy
July	82.53	15.82	1.65	Sandy
August	95.10	4.30	0.60	Sandy
September	94.30	4.43	1.27	Sandy
October	91.49	6.69	1.82	Sandy
November	90.37	4.67	4.96	Sandy
December	97.32	2.60	0.08	Sandy
January 1984	94.29	3.88	1.83	Sandy
February	84.80	14.90	0.30	Sandy
March	95.32	3.78	0.90	Sandy
April	96.36	2.64	1.00	Sandy
May	93.98	4.84	1.18	Sandy
June	85.72	12.29	1.99	Sandy
July	89.60	9.66	0.74	Sandy
August	93.63	5.40	0.97	Sandy

Table 4. Plankton abundance in the three sites during the study period ($n=10^{-3}/m^3$).

Month	Site I		Site II		Site III	
	Phyto-plankton	Zoo-plankton	Phyto-plankton	Zoo-plankton	Phyto-plankton	Zoo-plankton
September 1982	7.4	78.7	9.5	59.3	2.9	93.4
October	12.8	79.6	10.3	62.5	1.8	89.5
November	3.3	25.9	15.3	17.3	2.0	36.3
December	2.5	17.6	10.0	16.9	1.3	6.4
January 1983	32.6	83.5	12.3	34.5	1.5	29.5
February	21.3	89.7	17.8	63.7	3.1	39.5
March	14.1	86.3	5.5	24.7	5.1	67.6
April	48.4	52.7	5.0	24.5	6.5	14.5
May	78.3	46.3	11.5	45.0	8.7	10.7
June	42.0	21.2	18.0	23.1	2.7	17.7
July	43.1	117.9	7.5	52.0	3.5	73.0
August	17.2	67.2	16.6	34.5	1.5	66.0
September	6.5	63.0	12.5	48.3	4.0	102.5
October	15.0	67.3	5.8	42.5	4.3	147.3
November	3.2	24.0	2.0	27.8	1.1	50.2
December	5.3	12.7	6.0	10.0	2.5	8.5
January 1984	25.5	69.5	4.5	60.5	1.0	37.5
February	17.0	82.5	11.0	10.3	1.2	49.2
March	3.0	38.3	19.0	30.8	7.3	10.2
April	10.3	34.2	14.0	109.5	1.8	33.0
May	20.2	72.2	13.1	43.3	4.3	42.5
June	27.8	21.5	5.2	31.8	2.2	73.7
July	51.1	29.3	16.5	121.8	1.2	79.5
August	25.0	78.3	16.1	49.8	1.5	45.0

Table 5. Percentage composition of gastropod veliger in the zooplankton of the three study sites during the period of observation.

Month	Site I	Site II	Site III
September 1982	6.8	7.4	12.5
October	1.3	--	--
November	--	--	--
December	--	--	--
January 1983	7.3	3.5	2.5
February	12.3	4.2	12.5
March	14.1	8.1	2.2
April	7.6	3.4	3.4
May	12.0	5.6	1.5
June	10.0	14.3	1.0
July	11.1	6.7	3.5
August	4.8	15.9	4.5
September	7.9	10.4	4.5
October	--	--	9.3
November	--	--	--
December	--	--	--
January 1984	14.4	4.1	1.3
February	38.5	--	--
March	--	4.0	4.9
April	5.0	46.8	1.5
May	4.1	6.3	0.8
June	10.9	8.7	1.0
July	5.9	1.4	2.5
August	3.2	0.5	1.1

Table 6. Percentage occurrence of Balanus and Saccostrea infested specimens in the populations of C. (C.) cingulata.

Month	Balanus infested			Saccostrea infested		
	Site I	Site II	Site III	Site I	Site II	Site III
September 1982	1.22	0.82	2.44	0.27	--	--
October	4.46	2.15	--	0.36	--	--
November	3.19	2.66	--	--	--	--
December	5.19	8.77	--	0.55	--	--
January 1983	1.89	7.16	--	0.31	--	--
February	7.83	6.66	--	1.08	--	--
March	5.77	1.18	--	1.68	--	--
April	2.31	0.74	--	--	--	--
May	10.99	1.51	1.10	--	--	--
June	10.44	1.88	--	--	--	--
July	18.63	2.56	--	3.11	--	--
August	7.75	6.71	2.40	--	--	--
September	8.63	9.11	--	--	--	--
October	4.49	11.15	1.33	--	--	--
November	5.88	5.49	1.75	--	--	--
December	5.76	12.64	--	--	--	--
January 1984	8.98	6.41	--	--	--	--
February	8.81	8.33	--	--	--	--
March	9.97	6.72	--	--	--	--
April	8.23	7.69	--	--	--	--
May	9.97	6.72	--	--	--	--
June	2.60	1.95	--	--	--	--
July	2.91	1.13	3.60	0.29	--	--
August	10.00	2.76	3.12	1.54	--	--

Table 7. Month-wise occurrence of dead shells of C. (C.) cingulata and the number of shells with hermit crab Clibanarius sp.

Month	Dead shells in gm.			Number of hermit crabs		
	Site I	Site II	Site III	Site I	Site II	Site III
September 1982	7.7200	1.0250	4.3791	8	7	6
October	2.9260	7.6520	1.2000	12	21	1
November	26.7530	17.9280	--	67	32	--
December	22.5760	18.6253	4.0200	58	39	2
January 1983	16.9900	42.1901	3.7200	37	72	1
February	20.7400	14.5080	12.5700	80	26	5
March	9.0200	12.6700	2.0000	37	12	--
April	7.5000	16.5200	1.0000	7	12	--
May	4.2500	7.5200	3.2000	73	5	3
June	8.4500	7.5800	1.8000	16	10	1
July	27.3500	11.4200	2.0300	34	8	1
August	20.7850	32.7251	--	33	35	--
September	5.9500	16.8400	3.8700	9	17	3
October	52.2988	19.3200	6.5000	45	67	--
November	64.7800	15.8300	24.0000	112	22	12
December	16.7300	36.1000	4.0200	9	40	2
January 1984	50.4300	45.7200	18.2000	17	12	7
February	66.7284	55.7520	5.9000	47	37	2
March	46.7500	40.5650	7.5000	12	24	5
April	42.7200	34.7500	5.2000	57	22	4
May	46.2666	35.8510	4.0000	50	22	4
June	11.1222	17.9400	4.0030	10	7	5
July	22.8000	22.4600	7.0009	20	7	8
August	32.4000	7.3020	11.6000	48	19	8

Table 8. Scores assigned to various activity levels of C. (C.) cingulata.

Activity	Score	Description
Animal remained within the shell; upturned.	0	Inactive
Foot extended from the shell; not attached to the surface	1	Poor or low
Attached to the bottom of aquaria; not moving.	2	
Attached to side of aquaria below water line; not moving.	3	Moderate
Attached to side of aquaria above water line; not moving	4	High
Moving anywhere, below or above water line	5	

Table 9. Time taken for recovery by C. (C.) cingulata from 0‰ to ambient salinity.

Days of exposure	Time required in minutes		
	Site I	Site II	Site III
1	2	2	2
2	3	2	2
3	7	4	5
4	10	4	6
5	19	10	10
6	35	20	15
7	28	25	20
8	27	28	25
9	45	32	35
10	65	50	54

Table 10. Behaviour of C. (C.) cingulata to gradually raising water temperatures.

Sl. No.	Temp. °C	Behaviour	No. of snails used	No. of snails recovered	Recovery time
1.	32	Normally active	5	5	Immediate
2.	33	-do-	5	5	-do-
3.	34	-do-	5	5	-do-
4.	35	-do-	5	5	-do-
5.	36	-do-	5	5	-do-
6.	37	-do-	5	5	-do-
7.	38	Activity increases	5	5	-do-
8.	39	-do-	5	5	-do-
9.	40	-do-	5	5	-do-
10.	41	Head protruded; active movements	5	5	-do-
11.	42	-do-	5	5	5 minutes
12.	43	-do-	5	5	5 minutes
13.	44	Movement slows down	5	5	12 minutes
14.	45	-do-	5	5	30 minutes
15.	46	Head protruded and moves violently; shell does not move	5	5	120 minutes
16.	47	-do-	5	4	240 minutes
17.	48	Body withdrawn into the shell; no activity	5	4	320 minutes
18.	49	-do-	5	1	360 minutes

Table 11. Effect of water temperature on C. (C.) cingulata on exposure for one hour.

Sl. No.	Temp. °C	No. of snails used	No. of snails recovered	Time of recovery
1.	32	10	10	Immediate
2.	34	10	10	Immediate
3.	36	10	10	4 minutes
4.	38	10	10	10 minutes
5.	40	10	10	20 minutes
6.	42	10	10	60 minutes
7.	44	10	10	120 minutes
8.	46	10	10	150 minutes
9.	48	10	6	200 minutes
10.	50	10	--	--

Table 12. Distribution of C. (C.) cingulata in Vellar estuary and associated environmental parameters.

Station	Number of snails/m^2	Salinity (‰)	Dissolved O_2 (ml/l)	pH (water)	pH (Substratum)	Temperature (surface) °C	Algae	Organic carbon (mg/gm)	Sand (%)	Silt (%)	Clay (%)	Description of the substratum
1	--	20.15	4.01	7.9	7.3	30.2	Absent	6.3	98.41	0.02	1.57	Sandy
2	1044	22.15	4.23	7.8	7.7	30.1	Moderate	9.6	76.32	4.80	18.88	Sandy
3	2087	26.47	4.53	7.9	7.4	30.2	Scarce	7.6	69.08	3.59	27.33	Clayey sandy
4	--	25.83	4.57	8.0	7.8	30.5	Absent	12.6	17.01	12.70	70.29	Sandy clay
5	263	31.73	4.21	8.2	7.8	30.5	Absent	8.6	57.22	1.45	41.33	Clayey sandy
6	6252	32.76	4.05	8.1	7.9	30.1	Moderate	9.4	72.39	6.75	20.86	Clayey sandy
7	1733	33.72	4.67	8.0	8.0	30.1	Scarce	5.3	78.20	20.60	1.20	Sandy
8	2673	34.57	4.23	8.2	8.1	30.3	Moderate	6.1	82.53	1.65	15.82	Sandy
9	2210	34.36	4.91	8.1	8.0	30.6	Moderate	6.2	87.55	3.35	9.10	Sandy
10	12570	34.56	4.17	8.1	7.8	30.2	Heavy	7.0	89.52	3.40	7.08	Sandy

Table 13. Release and recapture of specimens of C. (C.) cingulata from different transects.

Time (hrs) of sampling	Colour of specimens found			
	Transect 1 (Green)	Transect 2 (Red)	Transect 3 (Yellow)	Transect 4 (White)
06 : 30	G : 300	R : 300	Y : 300	W : 300
10 : 30	G : 225	R : 178	Y : 125	W : 132
	W : 1	Y : 4	-	Y : 2
	R : 2			
14 : 30	G : 190	R : 243	Y : 212	W : 169
		G : 15	R : 27	Y : 7
		Y : 12	W : 2	
18 : 30	G : 190	R : 216	Y : 186	W : 155
		G : 12	R : 26	Y : 6
		Y : 19	W : 15	
06 : 30	G : 142	R : 176	Y : 226	W : 78
		G : 31	R : 27	Y : 12
		Y : 5	W : 12	

Fig. 27. Rainfall (in mm) at Porto Novo.

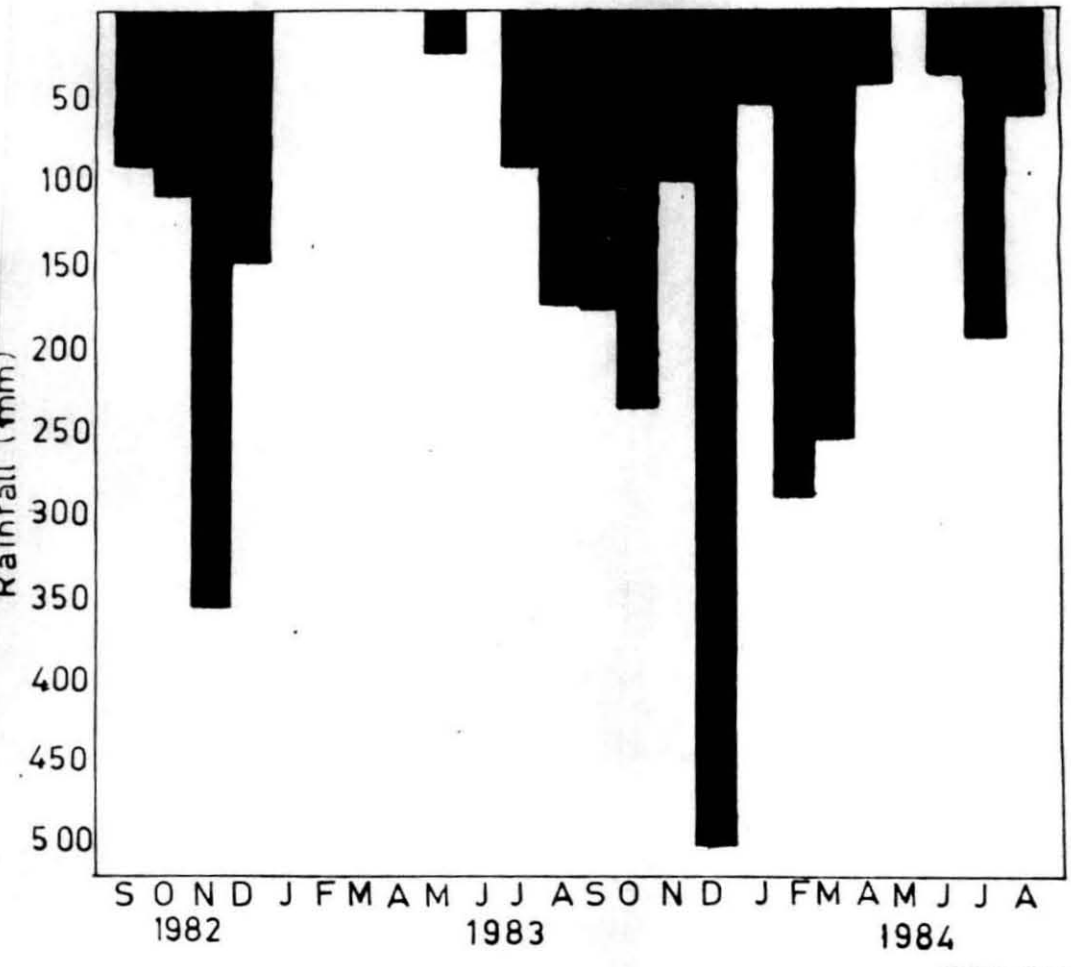

Rainfall (mm)
50
100
150
200
250
300
350
400
450
500
S O N D J F M A M J J A S O N D J F M A M J J A
1982
1983
1984

FIG 27

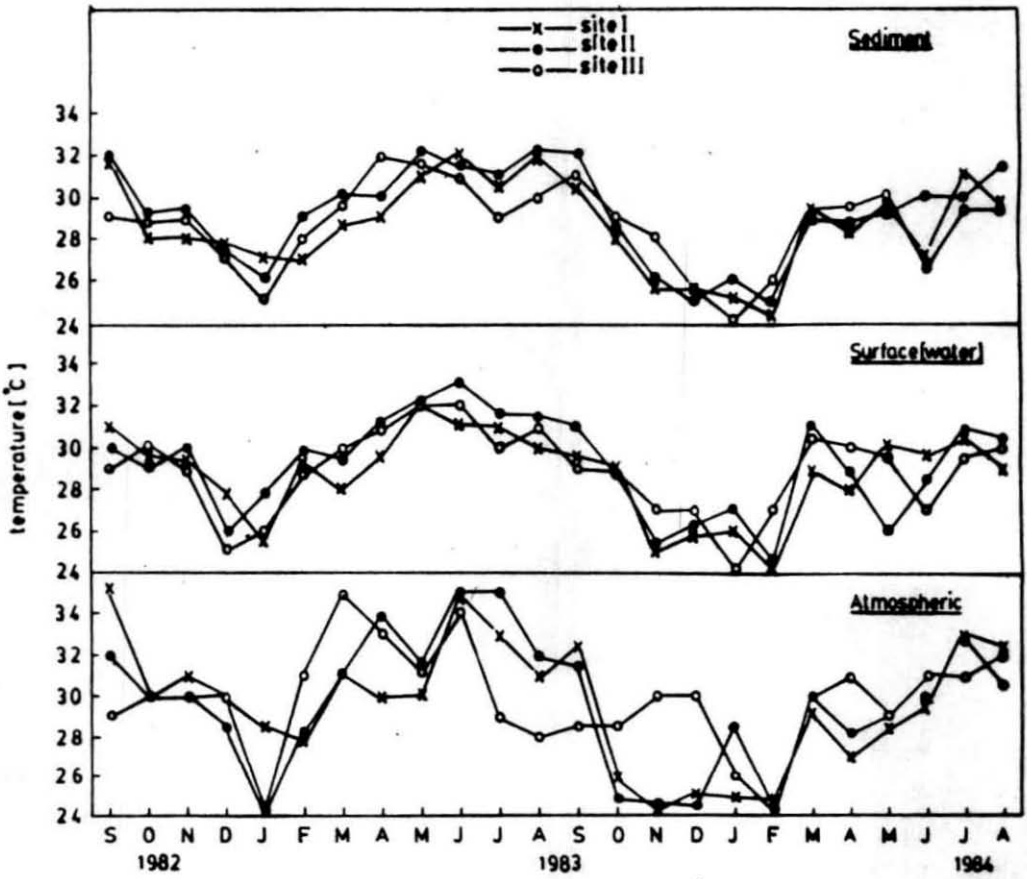

—x— site I
—●— site II
—○— site III
Sediment
Surface(water)
Atmospheric
temperature[℃]
34
32
30
28
26
24
S O N D J F M A M J J A S O N D J F M A M J J A
1982
1983
1984

FIG 28

Fig. 29. Salinity (‰)

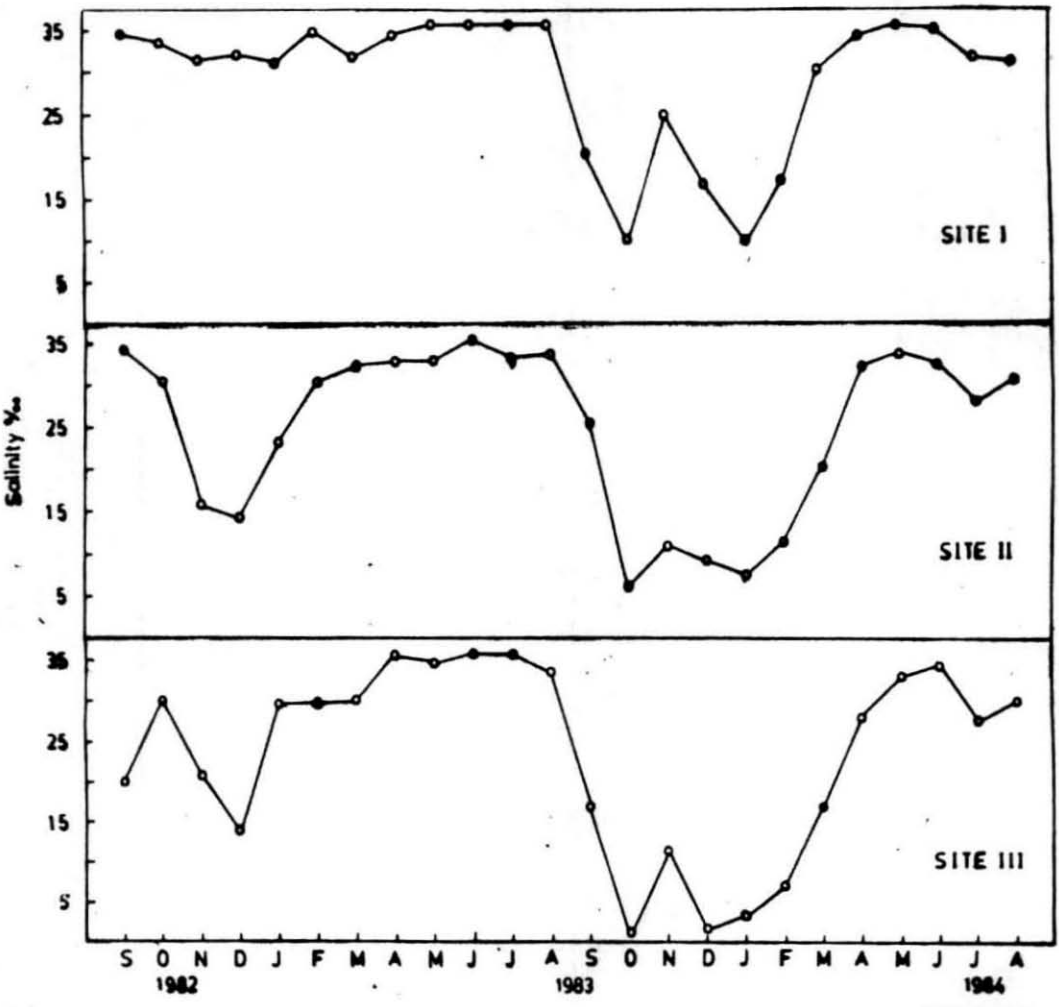

Salinity ‰
35
25
15
5
SITE I
SITE II
SITE III
S O N D J F M A M J J A S O N D J F M A M J J A
1982
1983
1984

FIG 29

Fig. 30. Dissolved oxygen content (ml/l)

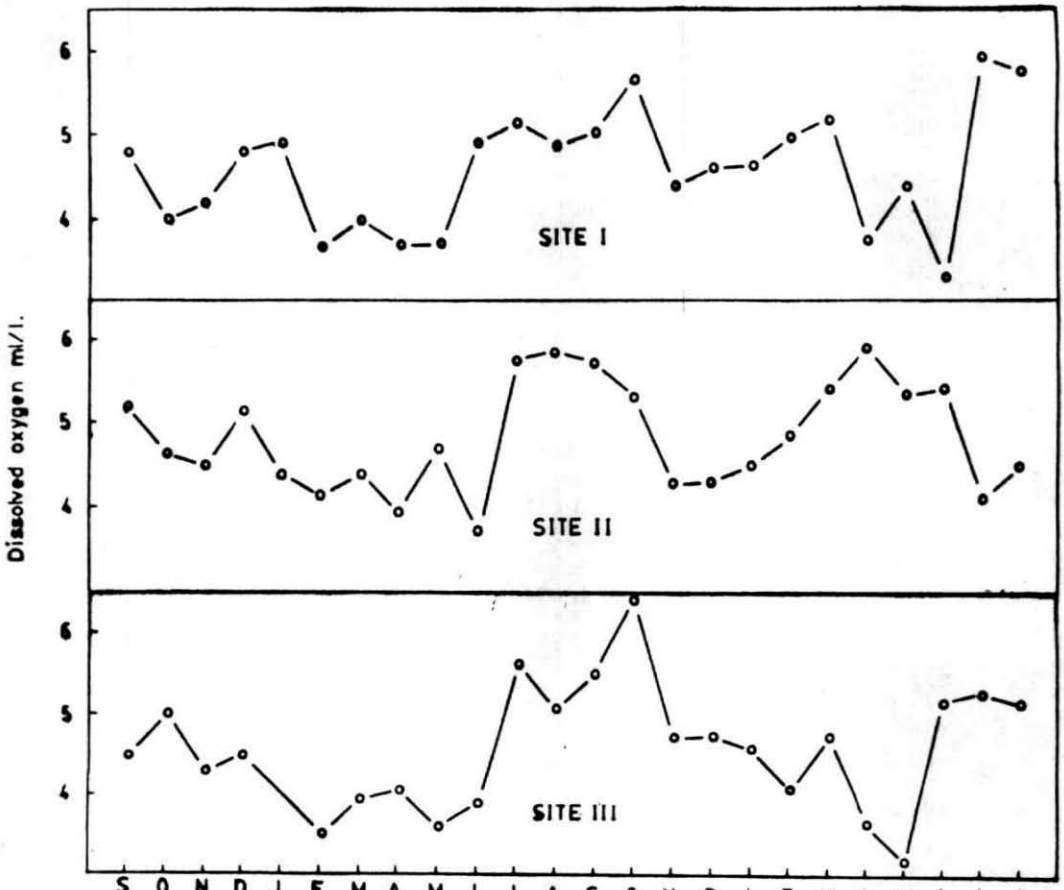

Dissolved oxygen ml/l.
6
5
4
SITE I
SITE II
SITE III
S O N D J F M A M J J A S O N D J F M A M J J A
1982
1983
1984

FIG 30

Fig. 31. pH values of water and sediment.

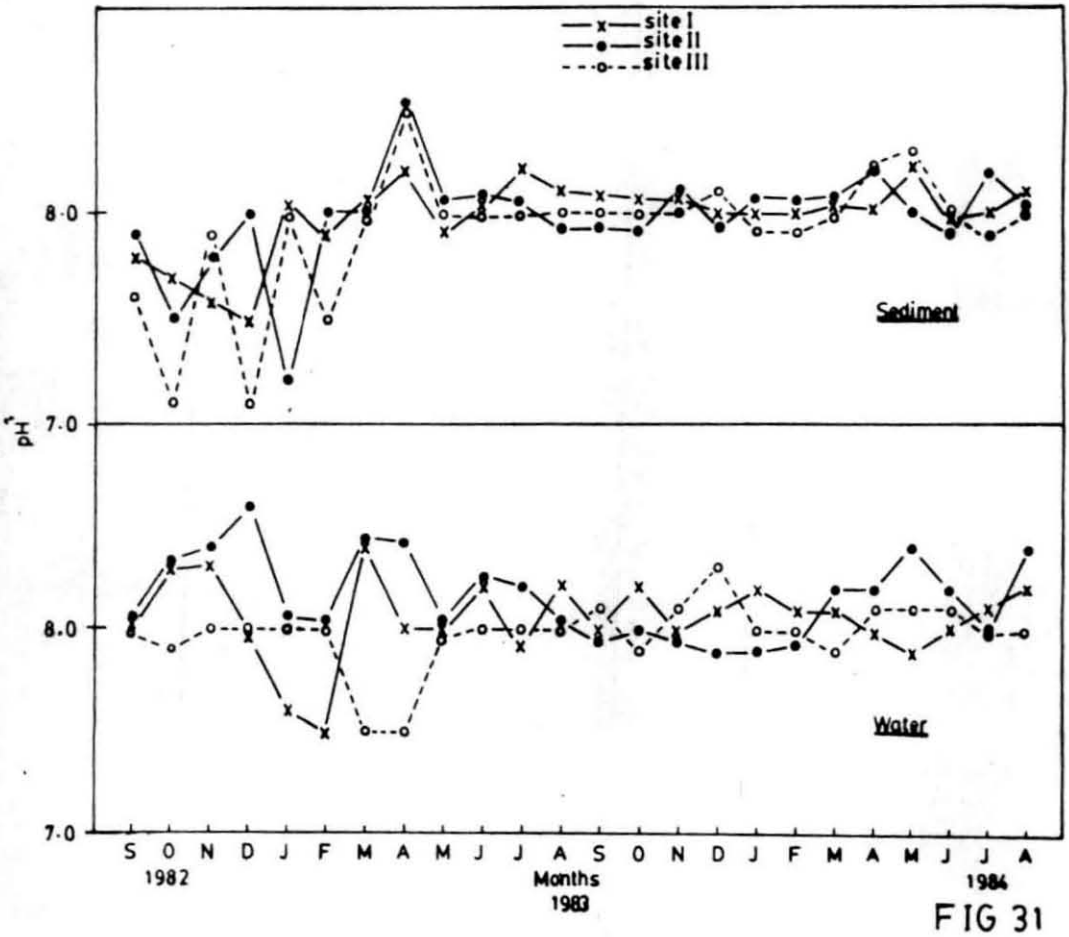

site I
site II
site III
8·0
7·0
pH
Sediment
8·0
7·0
Water
S O N D J F M A M J J A S O N D J F M A M J J A
1982
Months
1983
1984

FIG 31

Fig. 32. Organic carbon content of the sediment (mg/gm)

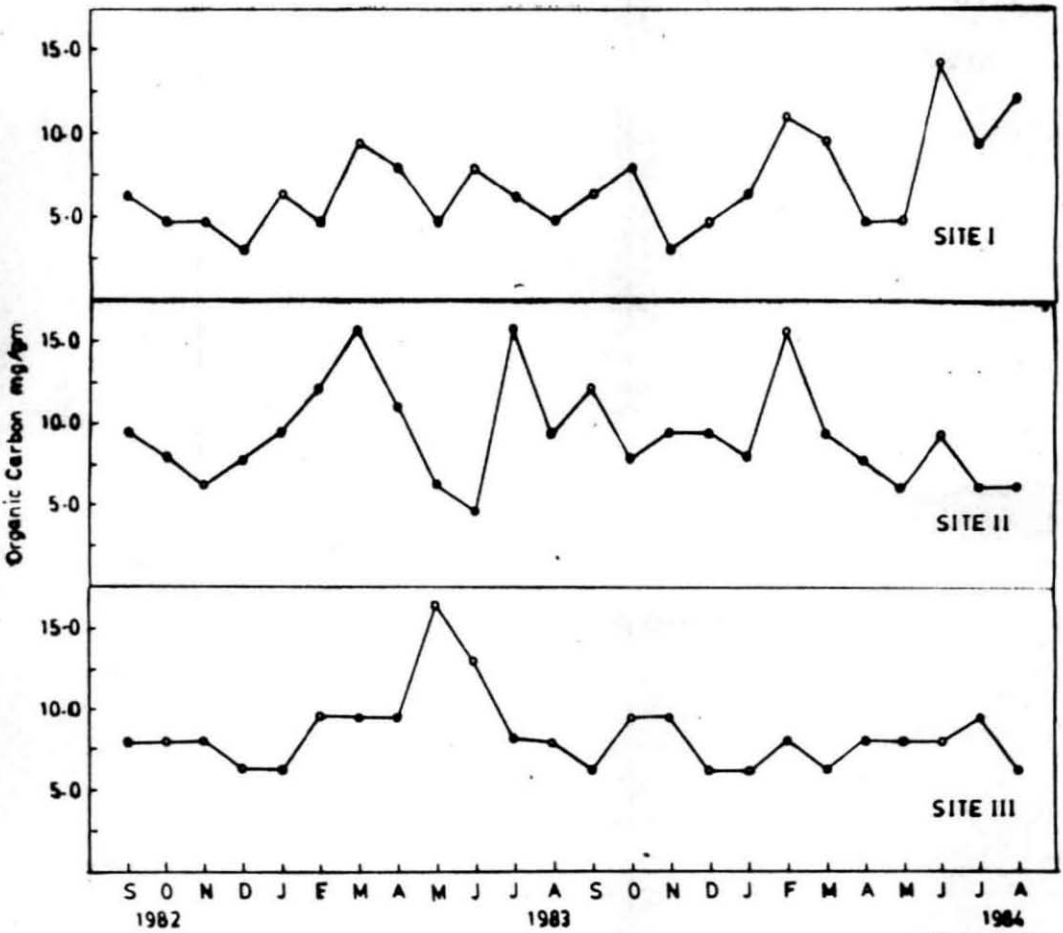

Organic Carbon mg/gm
15·0
10·0
5·0
SITE I
SITE II
SITE III
S O N D J F M A M J J A S O N D J F M A M J J A
1982
1983
1984

FIG 32

Fig. 33. Response of C. (C.) cingulata to changes in salinity.

A : Specimens from Site I

B : Specimens from Site II

C : Specimens from Site III

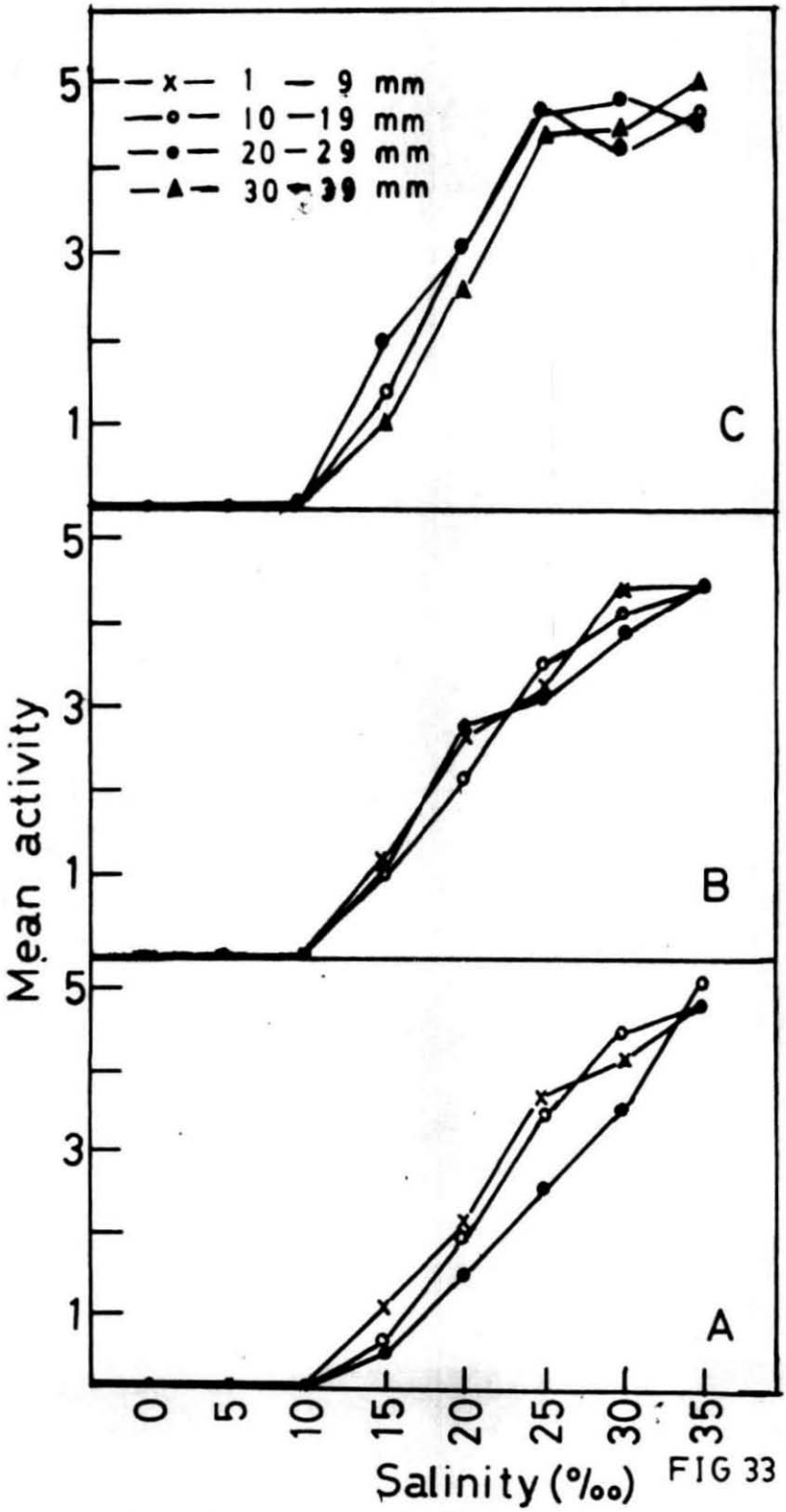

x— 1 — 9 mm
—o— 10 —19 mm
—•— 20 —29 mm
—▲— 30 —39 mm
5
3
1
C
B
A
Mean activity
0
5
10
15
20
25
30
35
Salinity (‰)

FIG 33

Fig. 34. Activity and mortality of C. (C.) cingulata from Site I in different salinities. (continuous line indicates activity; histogram represents mortality in percentage)

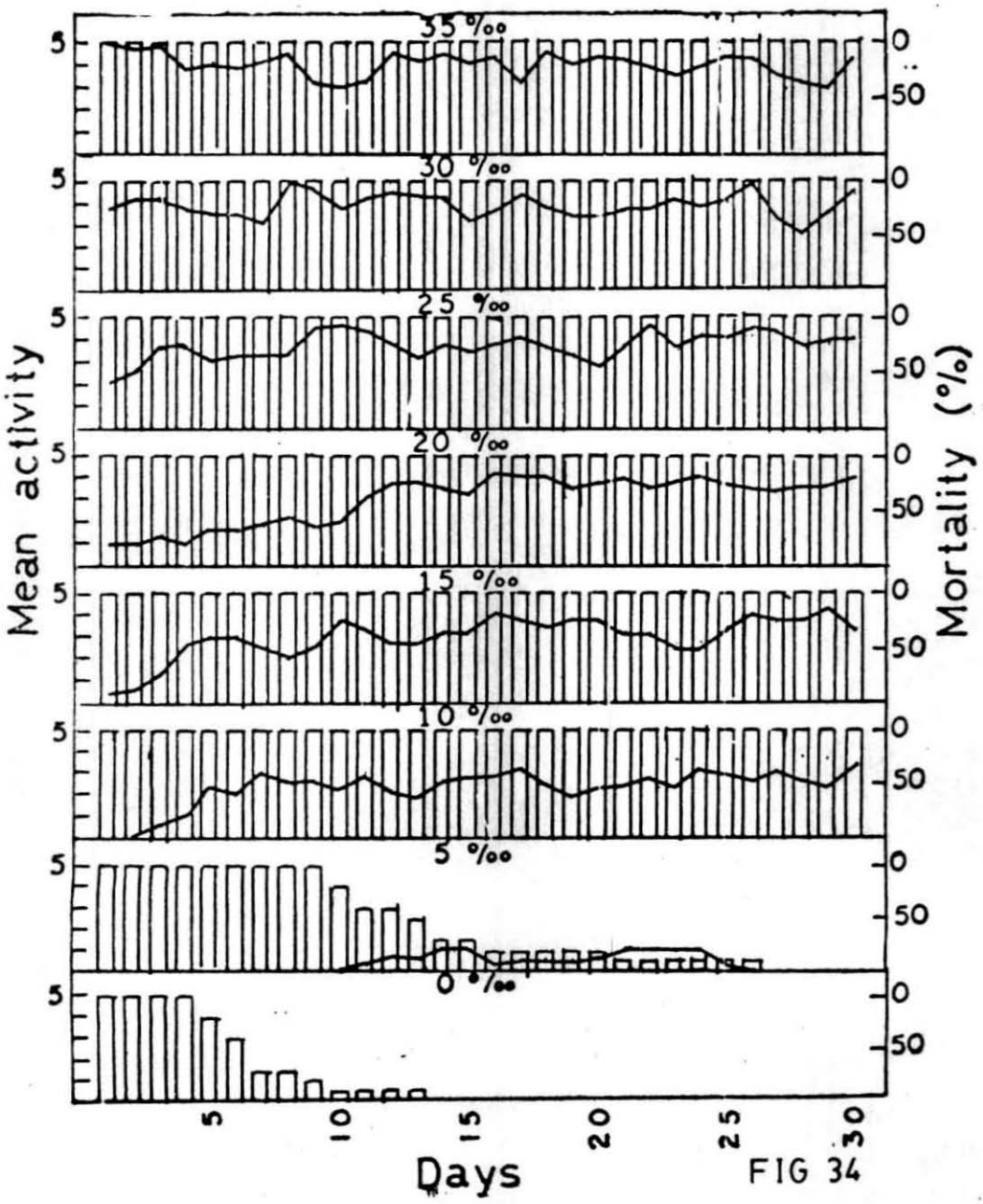

35 ‰
30 ‰
25 ‰
20 ‰
15 ‰
10 ‰
5 ‰
0 ‰
Mean activity
Mortality (%)
Days
5
10
15
20
25
30
0
50

FIG 34

Fig. 35. Activity and mortality of C. (C.) cingulata from Site II in different salinities (continuous line indicates activity; histogram represents mortality in percentage).

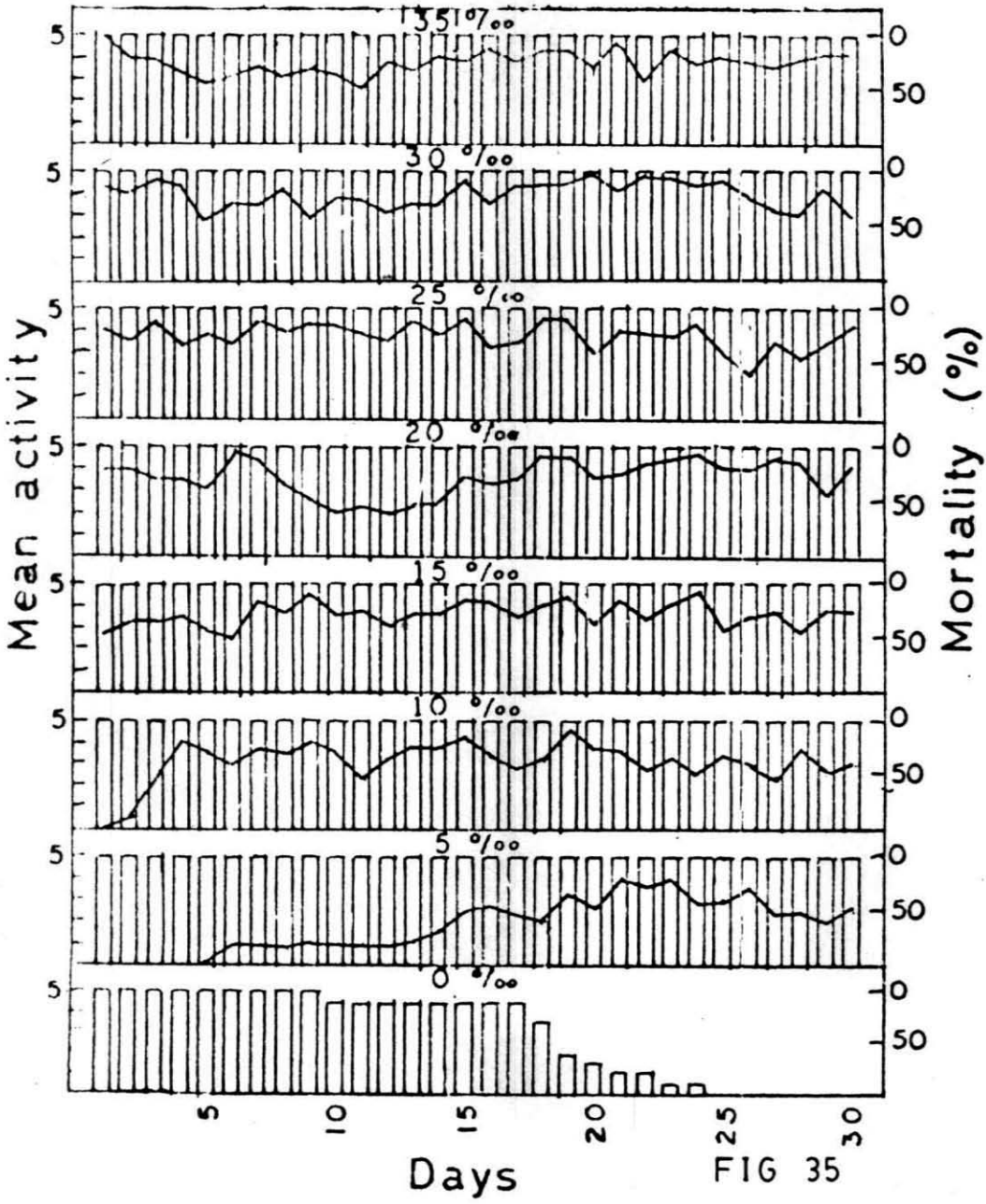

35 ‰
30 ‰
25 ‰
20 ‰
15 ‰
10 ‰
5 ‰
0 ‰
Mean activity
Mortality (%)
Days
5
10
15
20
25
30
0
50

FIG 35

Fig. 36. Activity and mortality of C. (C.) cingulata from Site III in different salinities. (continuous line indicates activity; histogram represents mortality in percentage)

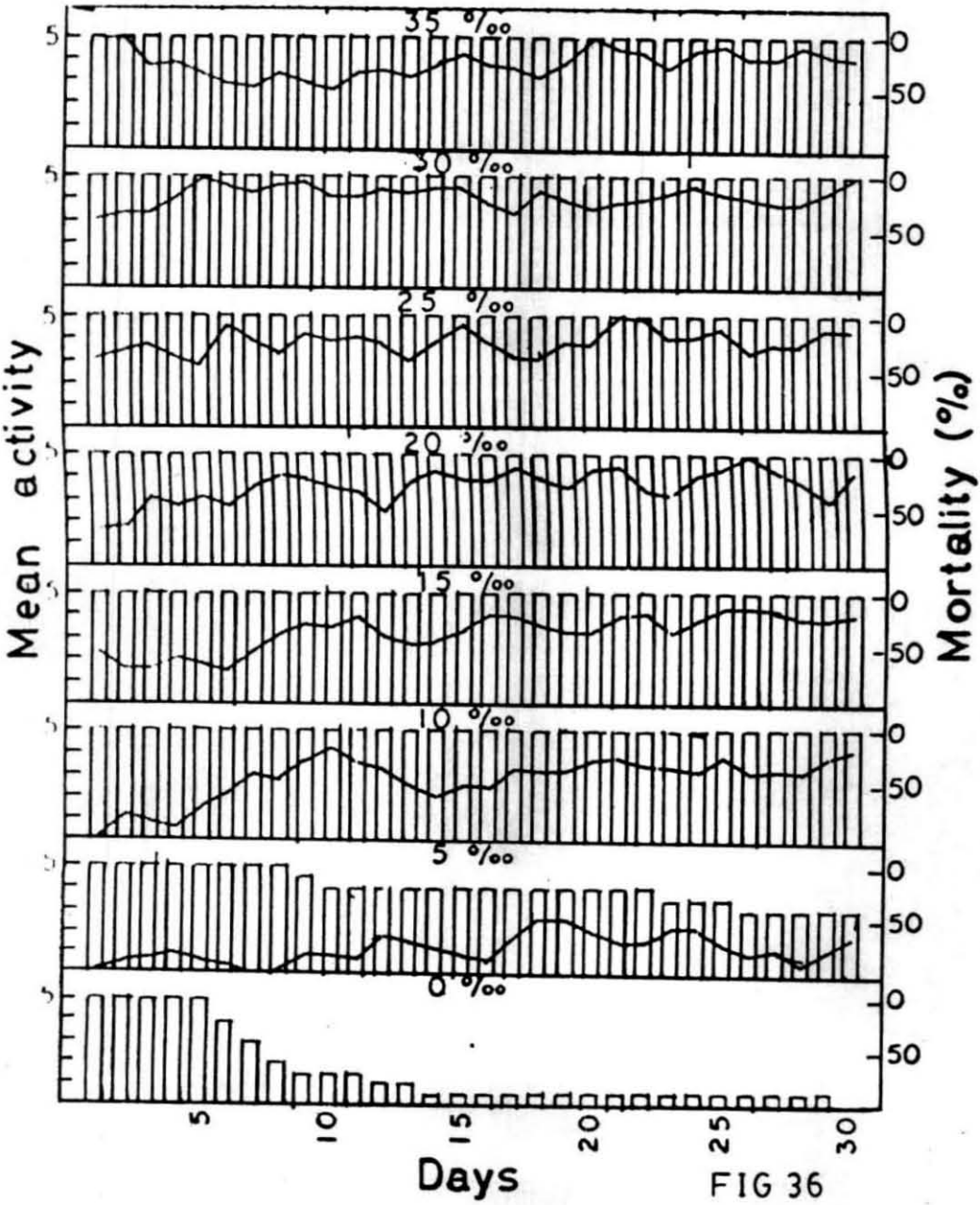

35 ‰
30 ‰
25 ‰
20 ‰
15 ‰
10 ‰
5 ‰
0 ‰
Mean activity
Mortality (%)
Days
5
10
15
20
25
30
0
50

FIG 36

Fig. 37. Water-loss in percentage in C. (C.) cingulata on successive days of exposure. (weight loss = water-loss)

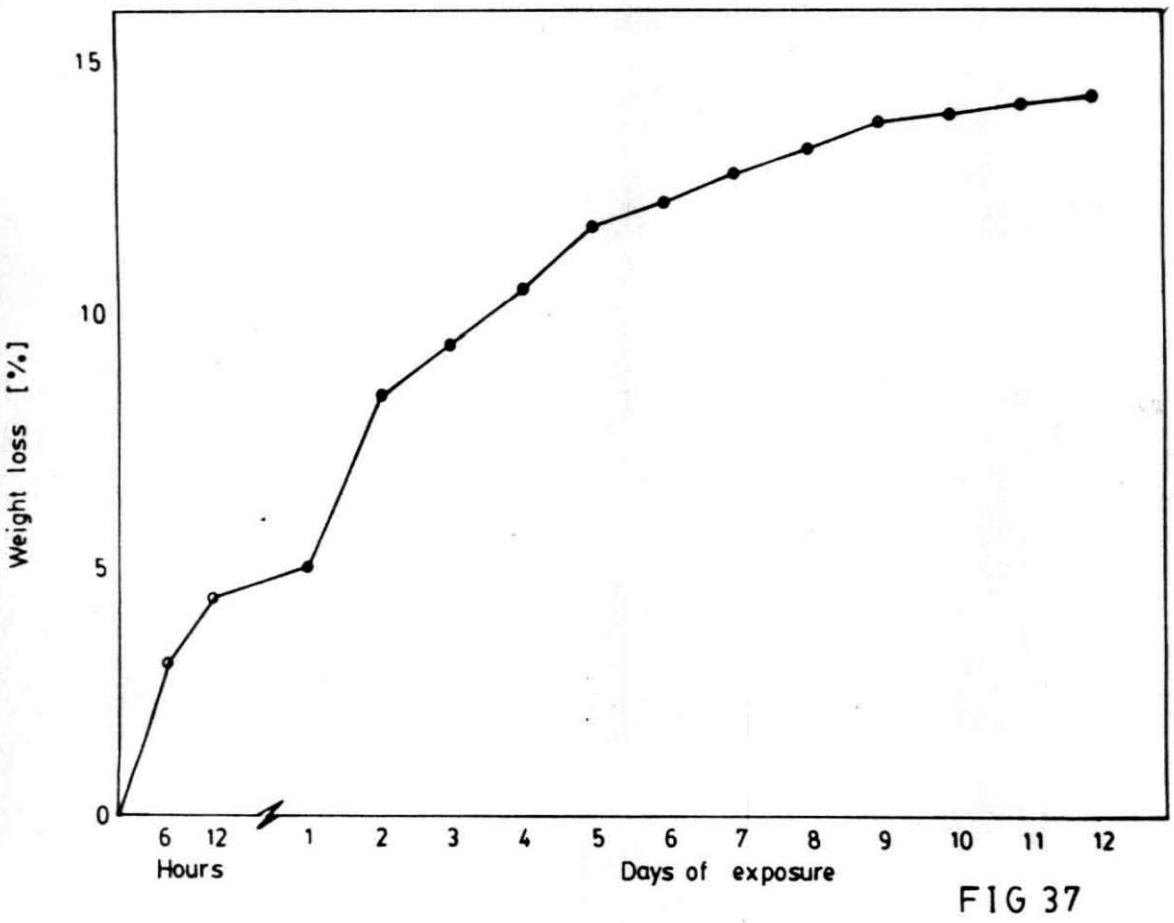

15
10
5
0
Weight loss [%]
6
12
Hours
1
2
3
4
5
6
7
8
9
10
11
12
Days of exposure

FIG 37

Fig. 38. Survival (in percentage) of C. (C.) cingulata on successive days of exposure.

Fig. 39. Mortality (in percentage) in C. (C.) cingulata and water-loss in percentage (weight loss = water-loss).

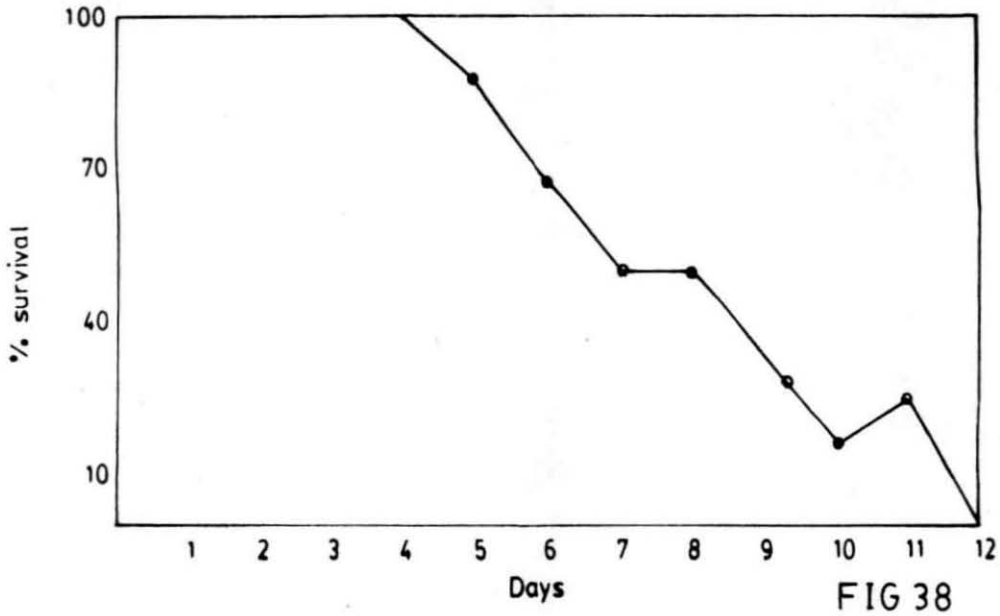

100
70
40
10
% survival
1
2
3
4
5
6
7
8
9
10
11
12
Days

FIG 38

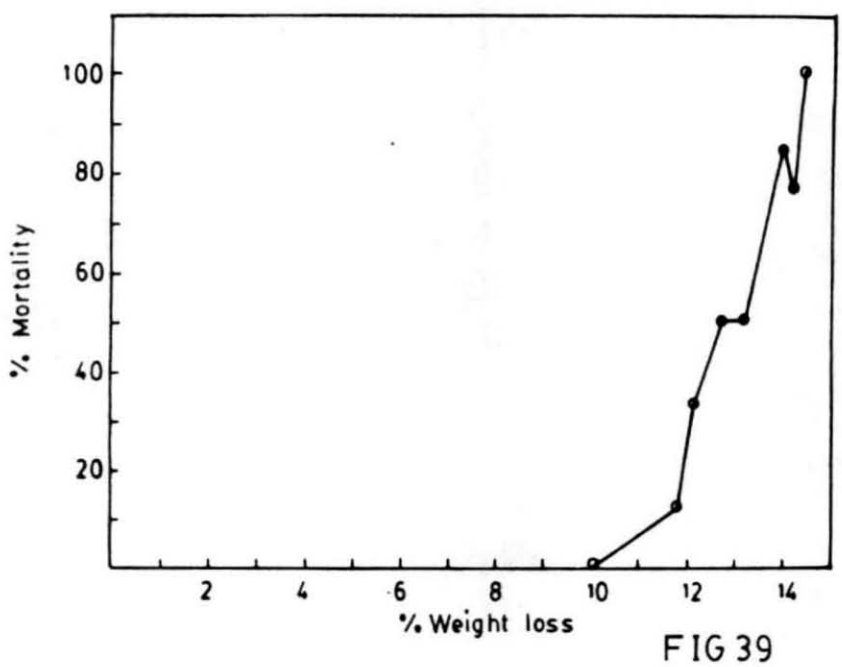

100
80
60
40
20
% Mortality
2
4
6
8
10
12
14
% Weight loss

FIG 39

Fig. 40. Percentage of water-loss and net water-loss in C. (C.) cingulata on successive days of exposure.

Fig. 41. Actual weight loss (in mg) and water-loss in percentage in different size groups of C. (C.) cingulata after 24 hours of exposure. (weight loss = water-loss)

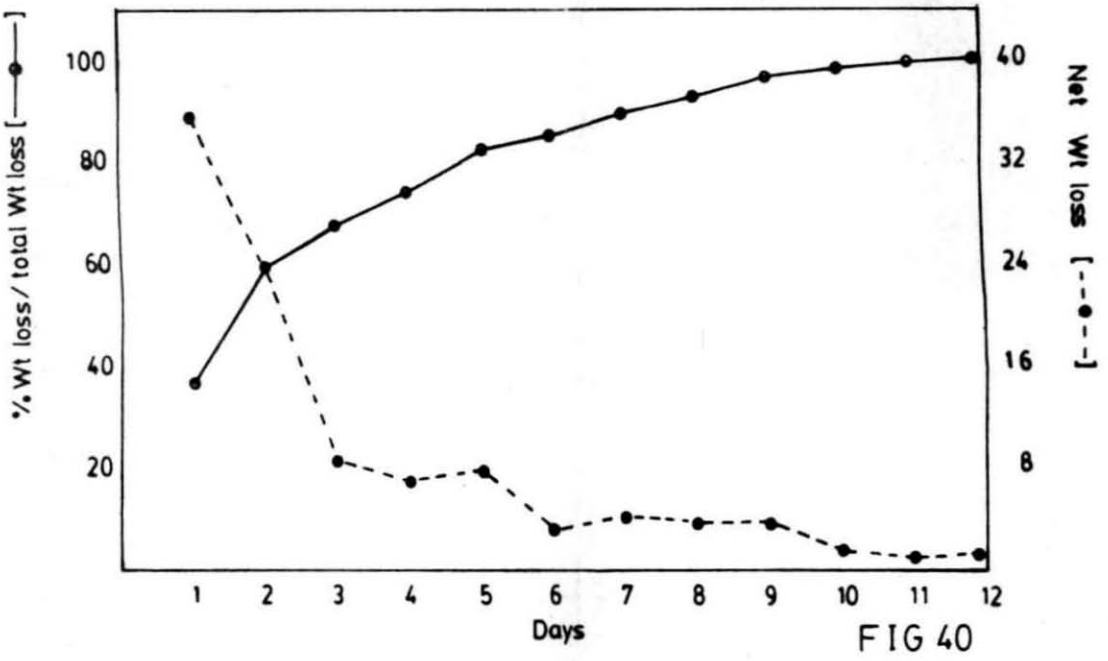

% Wt loss / total Wt loss [——●——]
Net Wt loss [- - -●- - -]
100
80
60
40
20
40
32
24
16
8
1
2
3
4
5
6
7
8
9
10
11
12
Days

FIG 40

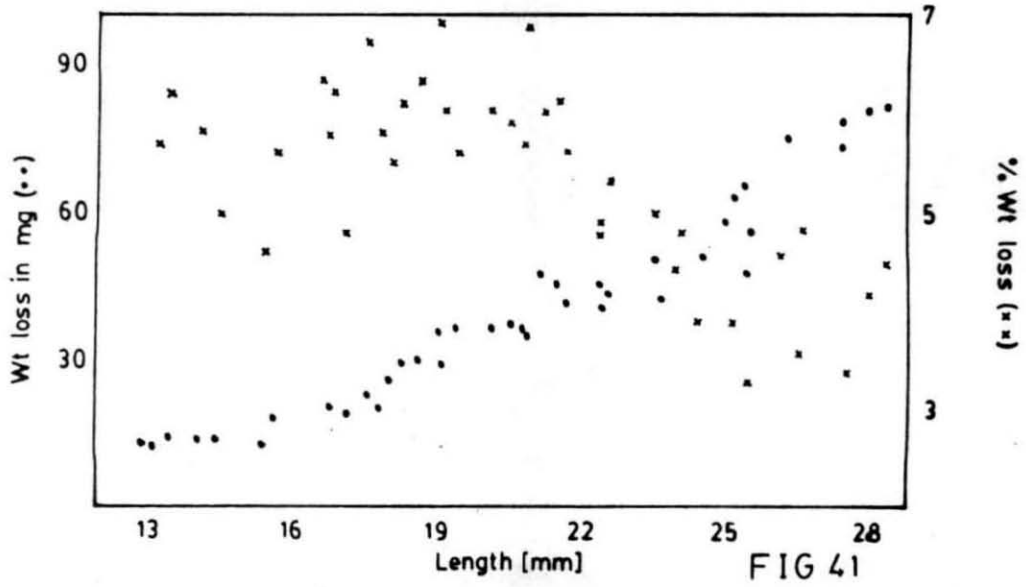

Wt loss in mg (••)
% Wt loss (××)
90
60
30
7
5
3
13
16
19
22
25
28
Length [mm]

FIG 41

Fig. 42. A) log actual weight loss in relation to log weight in C. (C.) cingulata after 24 hours of exposure.

B) log water-loss per unit mg weight in relation to log weight in C. (C.) cingulata after 24 hours of exposure. (weight loss = water-loss)

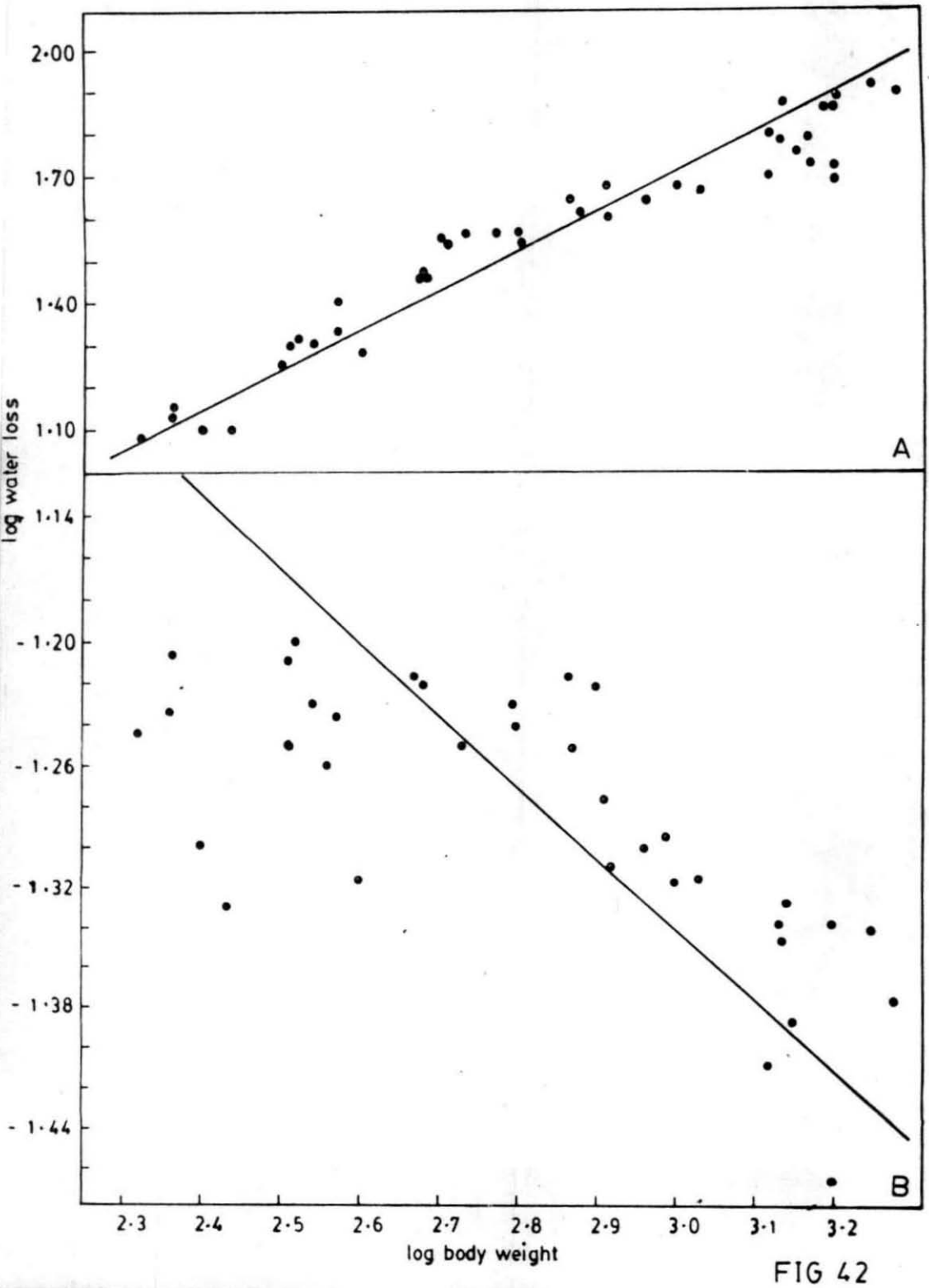

2·00
1·70
1·40
1·10
A
log water loss
1·14
- 1·20
- 1·26
- 1·32
- 1·38
- 1·44
B
2·3
2·4
2·5
2·6
2·7
2·8
2·9
3·0
3·1
3·2
log body weight

FIG 42

Fig. 43. Time taken for recovery (in minutes) by C. (C.) cinculata after exposure.

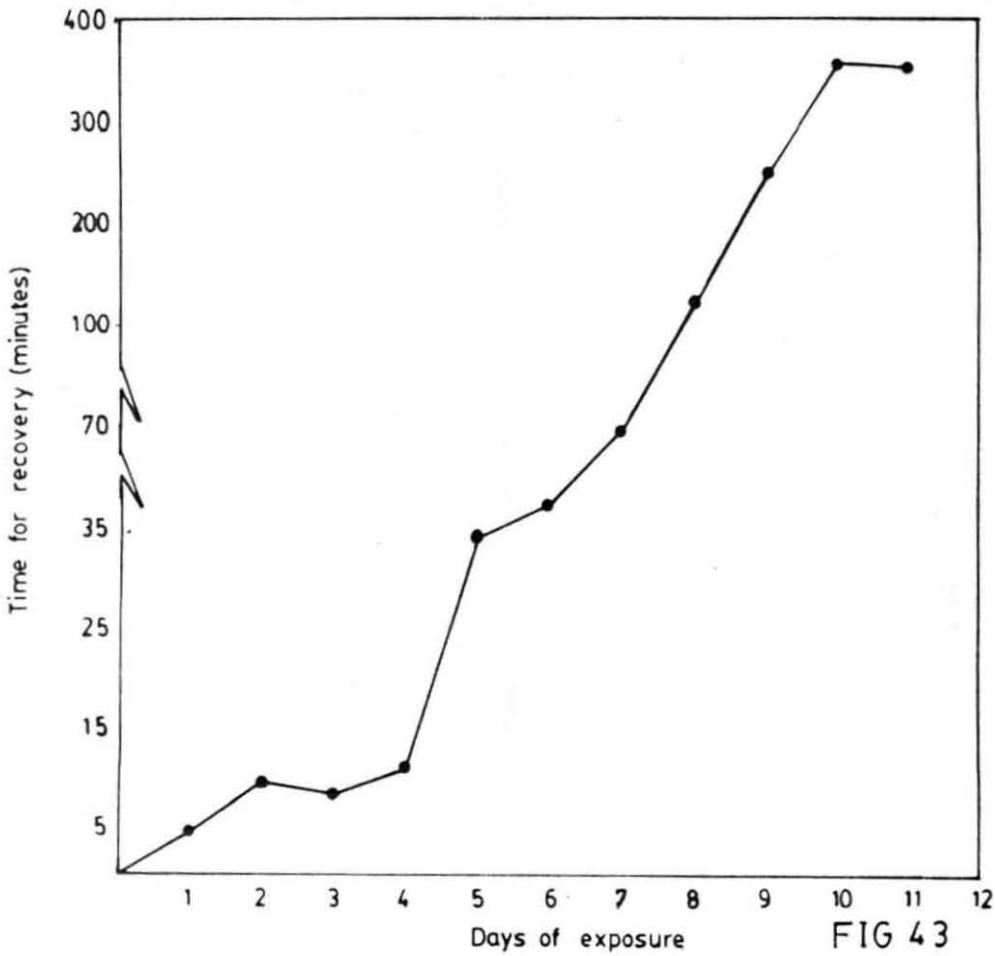

400
300
200
100
70
35
25
15
5
Time for recovery (minutes)
1
2
3
4
5
6
7
8
9
10
11
12
Days of exposure

FIG 43

Fig. 44. Map of the Vellar estuary showing location of different stations for sampling of C. (C.) cingulata

A : The Vellar mouth in 1983-'84

B : Mouth of Chinnavaykal

BS : C.A.S. in Marine Biology

LH : Light house

RS : Railway station

1 - 10 : Sampled Stations

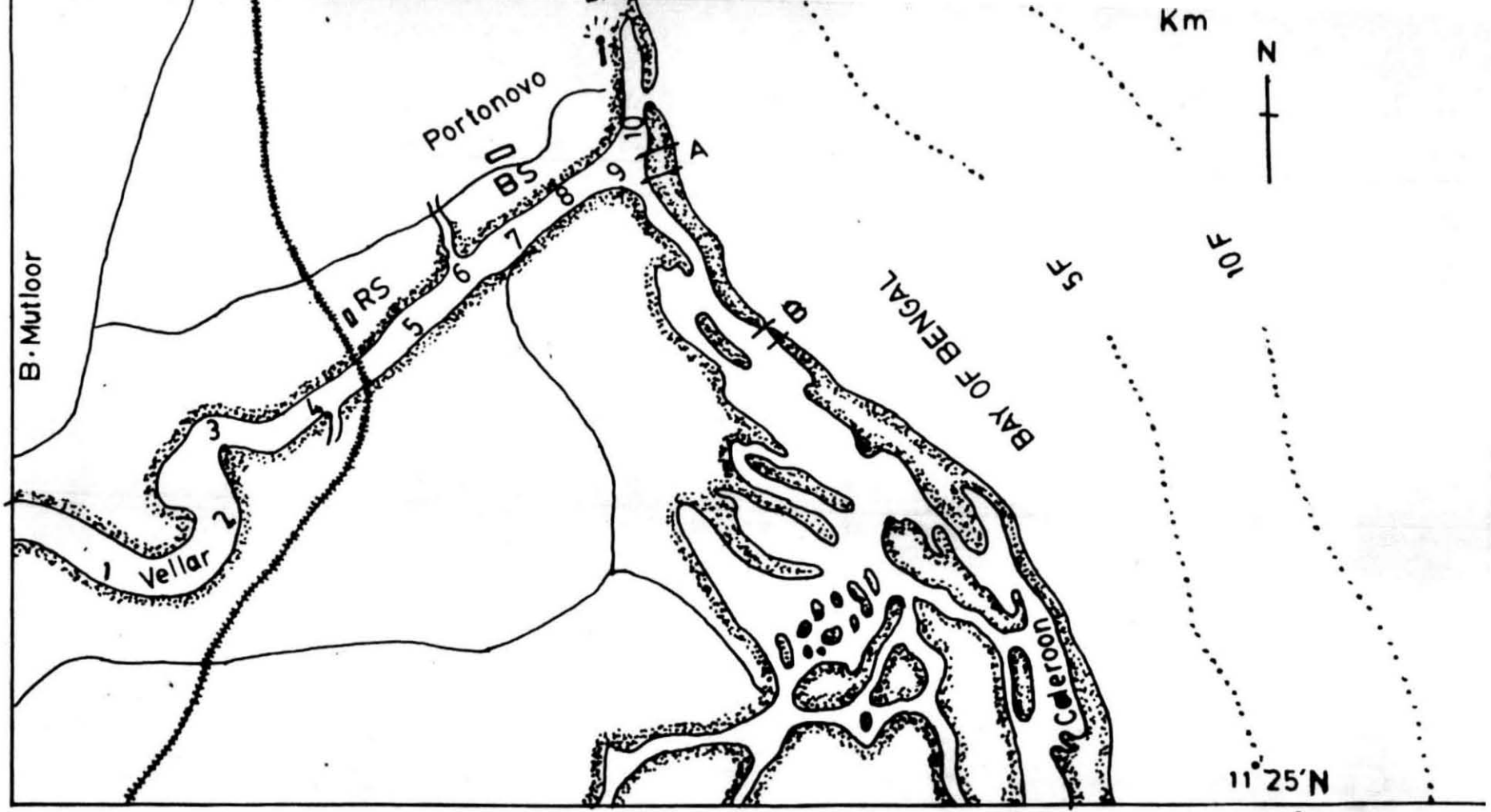

Km
N
Portonovo
BS
RS
A
B
1
2
3
4
5
6
7
8
9
10
B. Mutloor
1 Vellar
BAY OF BENGAL
SF
10F
Cuddalore
11°25'N
79°50'E

FIG 44

Fig. 45. Distribution of C. (C.) cingulata at different tide levels.

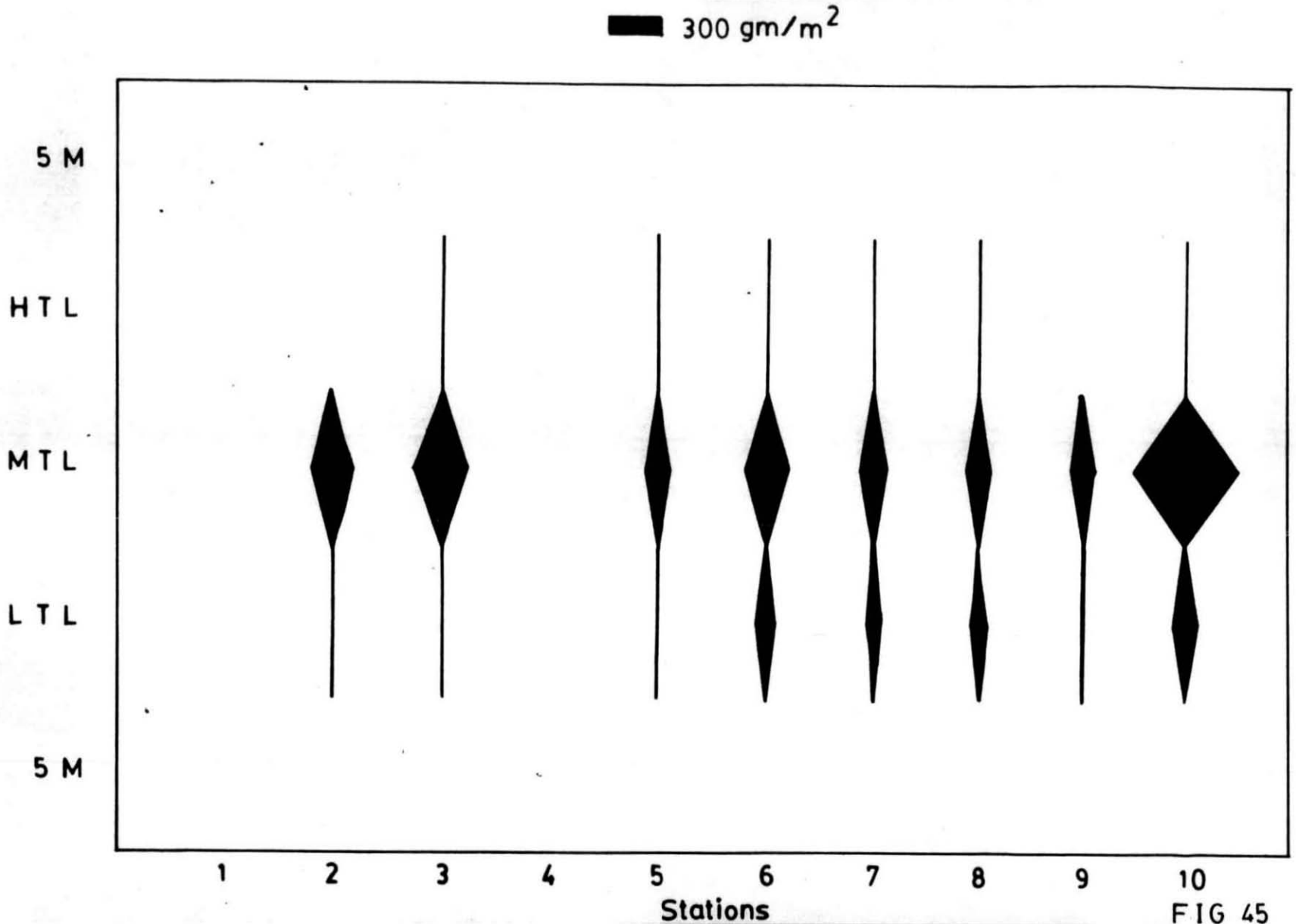
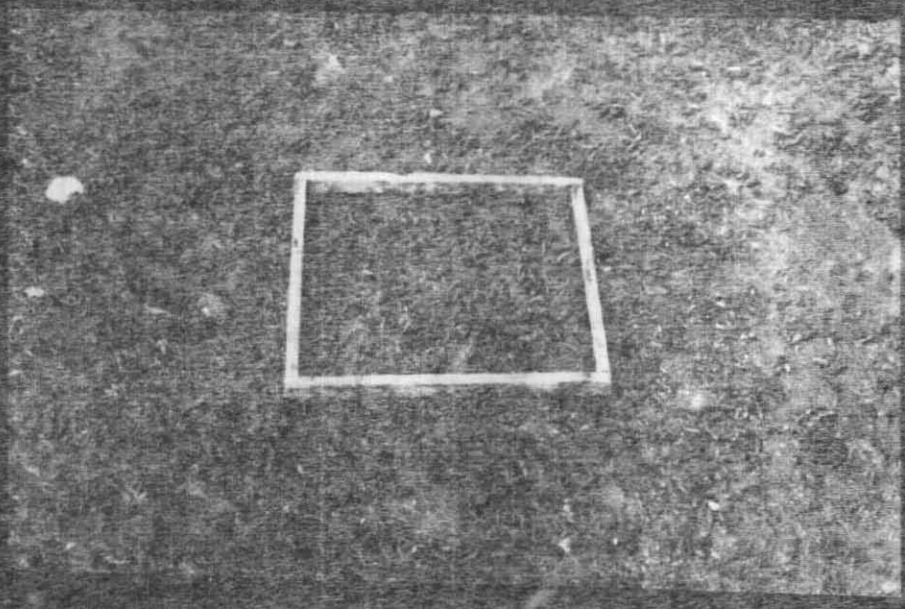


FIG 45

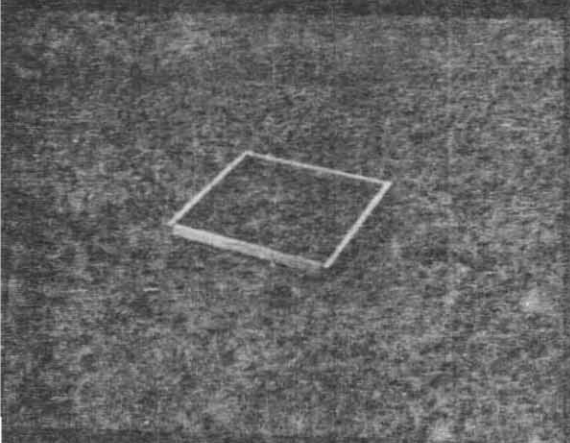
Fig. 46. Population of C. (C.) cingulata at Site I

Fig. 47. Population of C. (C.) cingulata at Site II

Fig. 48. Population of C. (C.) cingulata at Site III



46



47

48

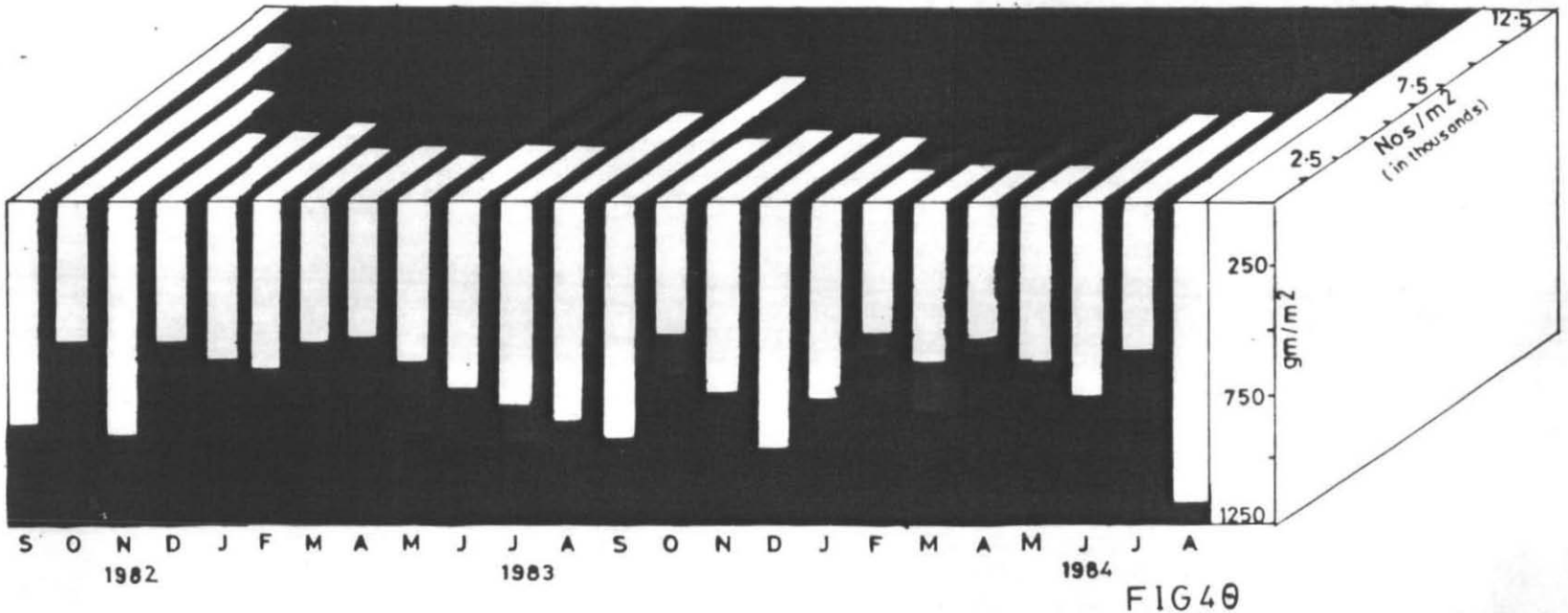

12·5
7·5
2·5
Nos/m2
(in thousands)
250
750
1250
gm/m2
S O N D J F M A M J J A S O N D J F M A M J J A
1982
1983
1984

FIG4θ

Fig. 50. Length composition of the population of C. (C.) cingulata at Site I (SD and mean length are given and the latter is connected)

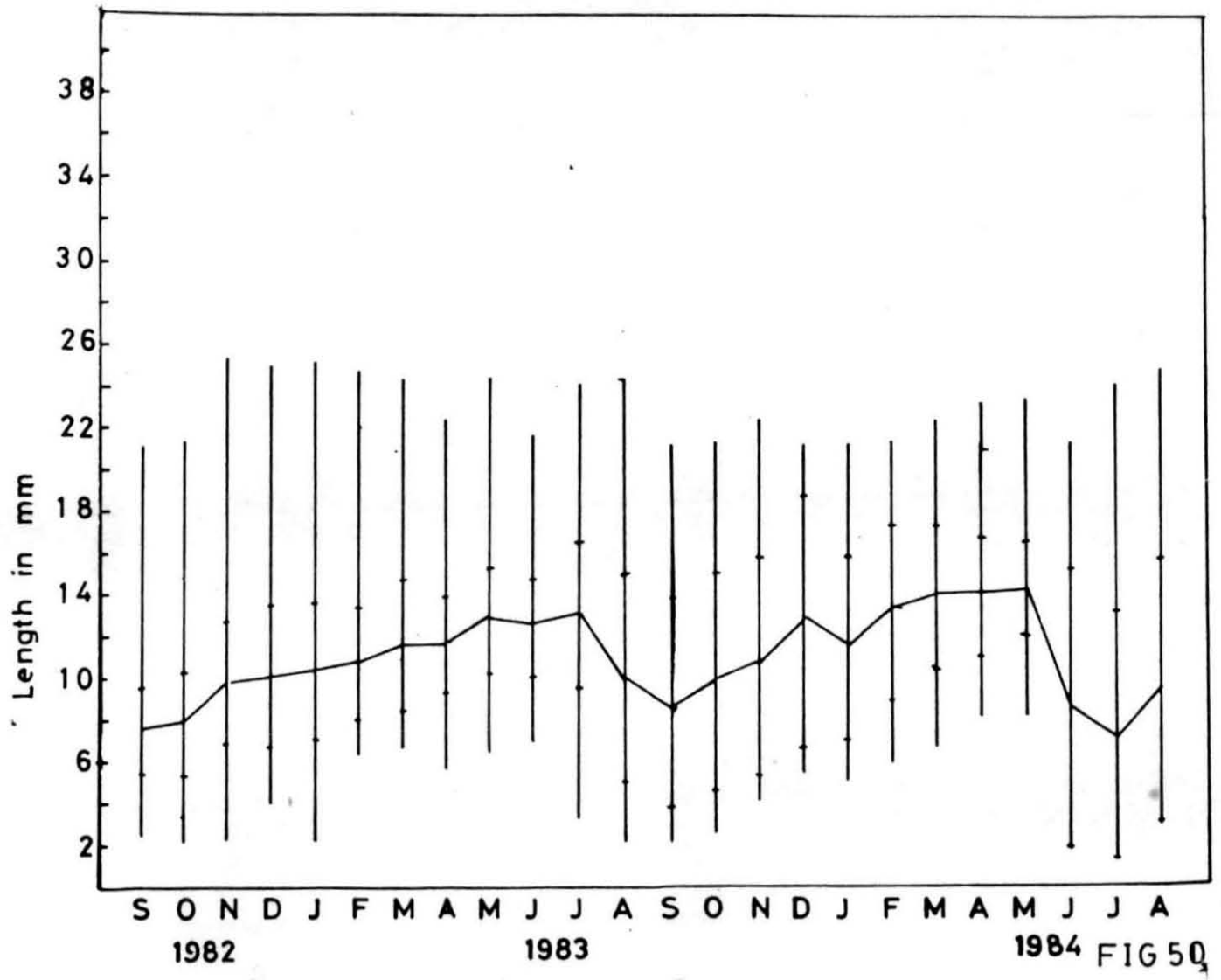

38
34
30
26
22
18
14
10
6
2
Length in mm
S O N D J F M A M J J A S O N D J F M A M J J A
1982
1983
1984

FIG 50

Fig. 51. Density of C. (C.) cingulata (by weight in gm and numbers in thousands/m^2) in Site II.

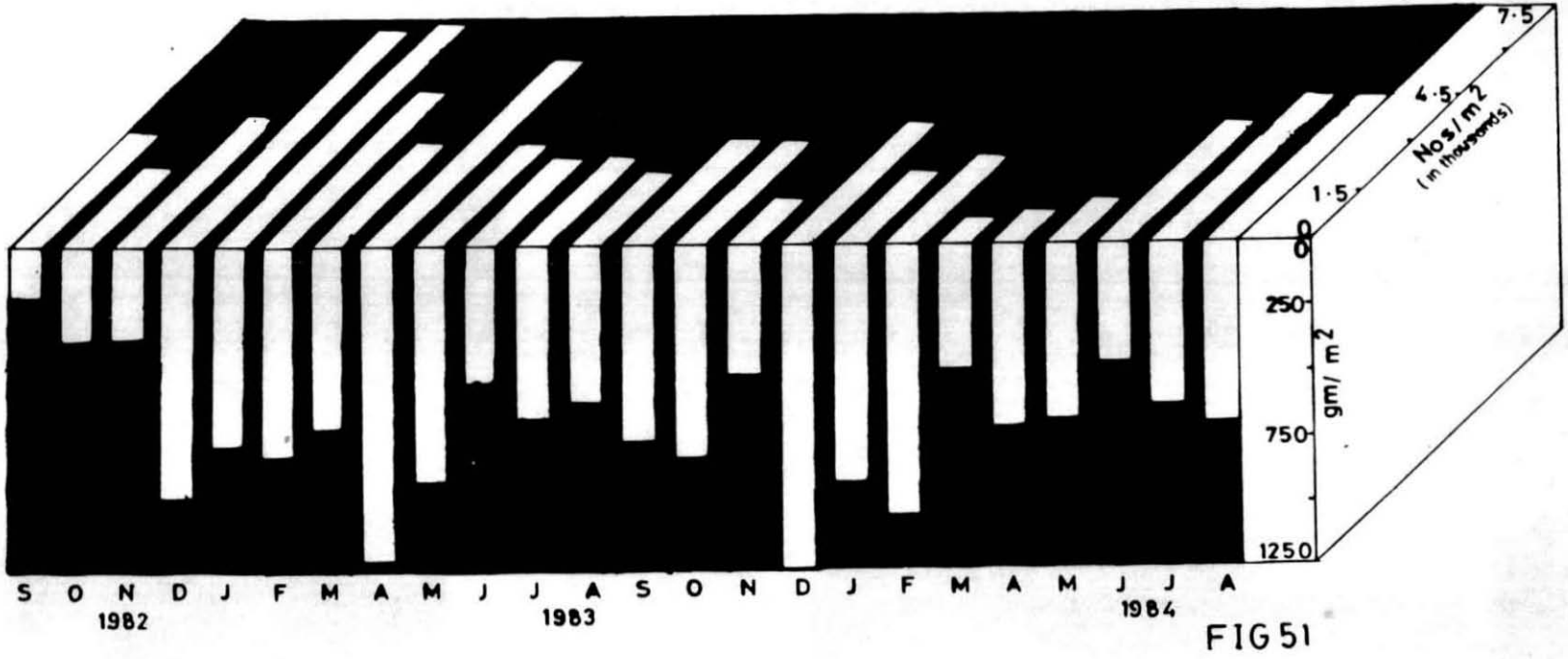

7·5
4·5
Nos/m2
(in thousands)
1·5
0
250
750
1250
gm/m2
S O N D J F M A M J J A S O N D J F M A M J J A
1982
1983
1984

FIG 51

Fig. 52. Length composition of the population of C. (C.) cingulata at Site II. (SD and mean length are given and the latter is connected)

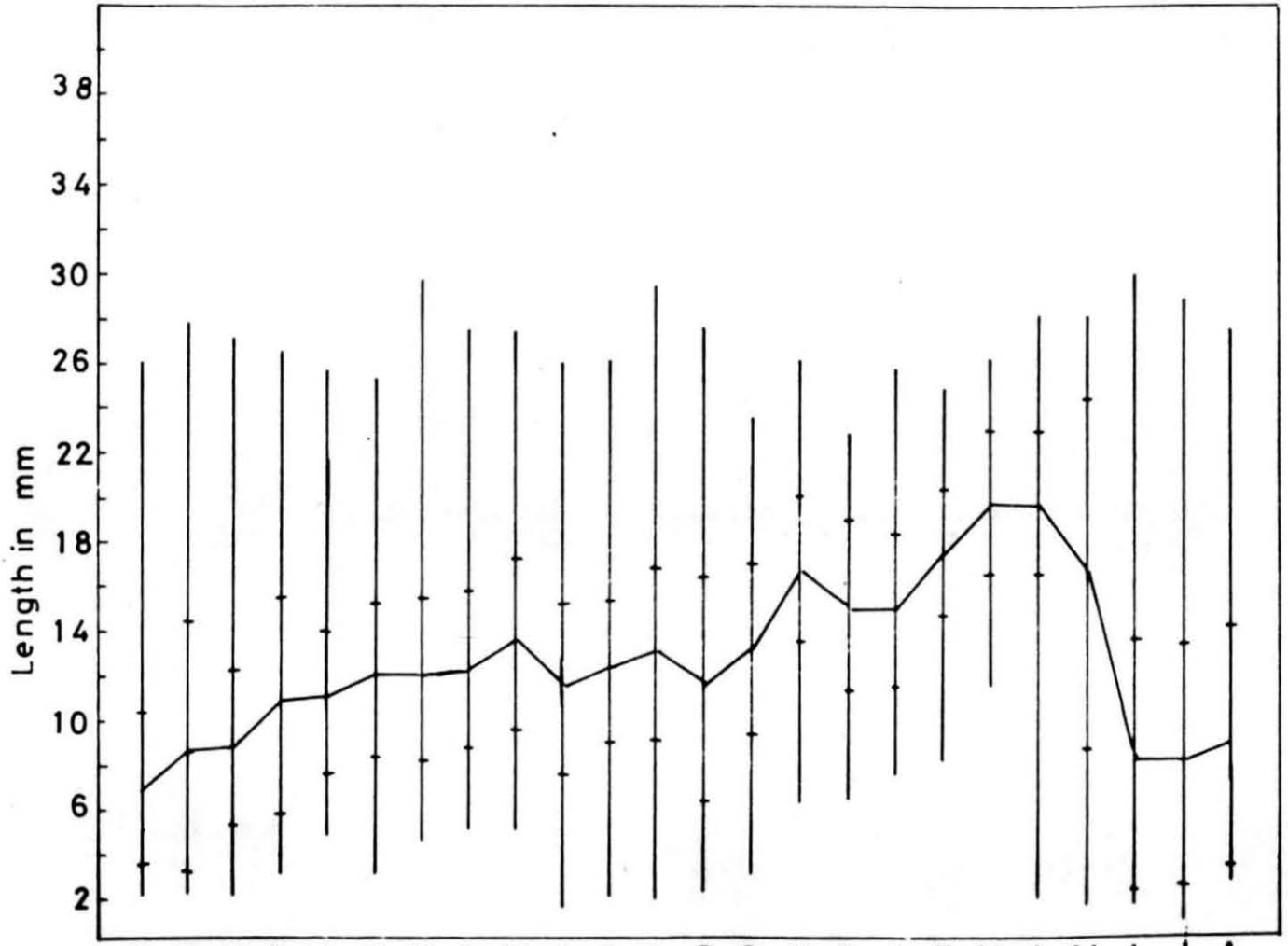

Length in mm
38
34
30
26
22
18
14
10
6
2
S O N D J F M A M J J A S O N D J F M A M J J A
1982
1983
1984

FIG 52

Fig. 53. Density of C. (C.) cingulata (by weight in gm and by numbers/m^2) at Site III.

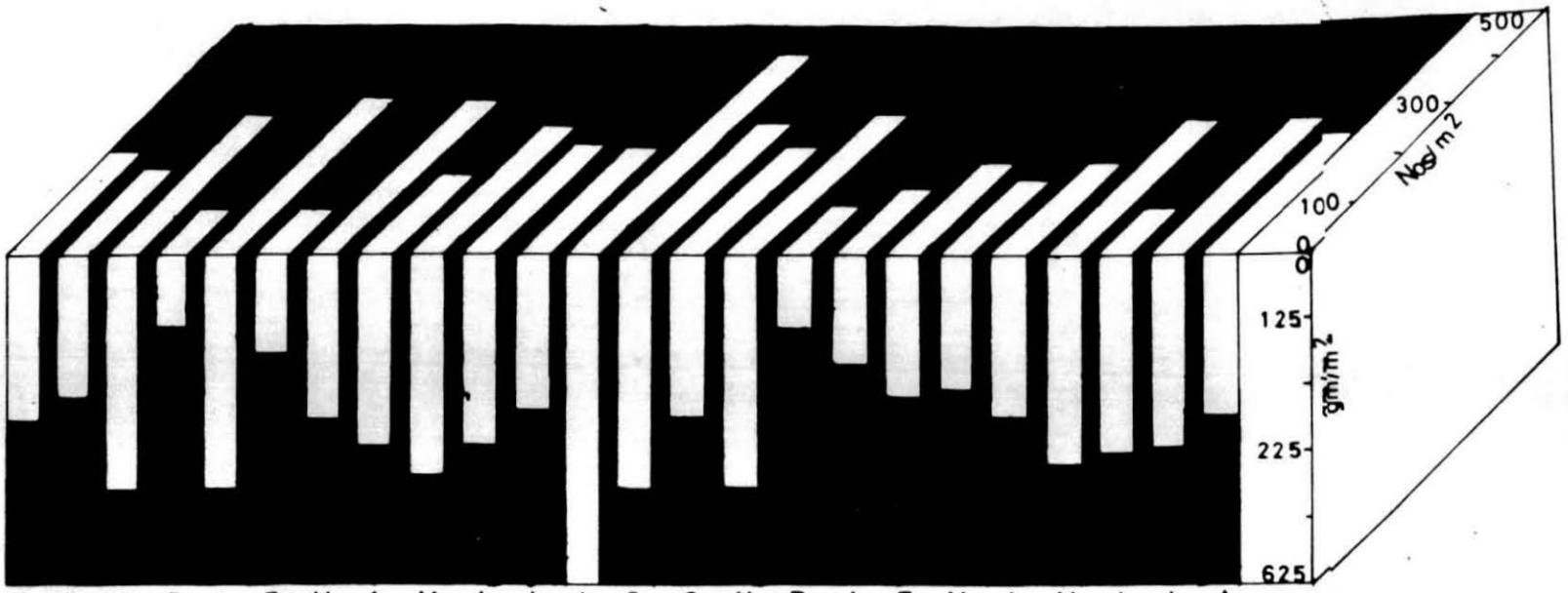

500
300
100
Nos/m2
125
225
625
gm/m2
S O N D J F M A M J J A S O N D J F M A M J J A
1982
1983
1984

FIG 53

Fig. 54. Length composition of the population of C. (C.) cingulata at Site III. (SD and mean length are given and the latter is connected).

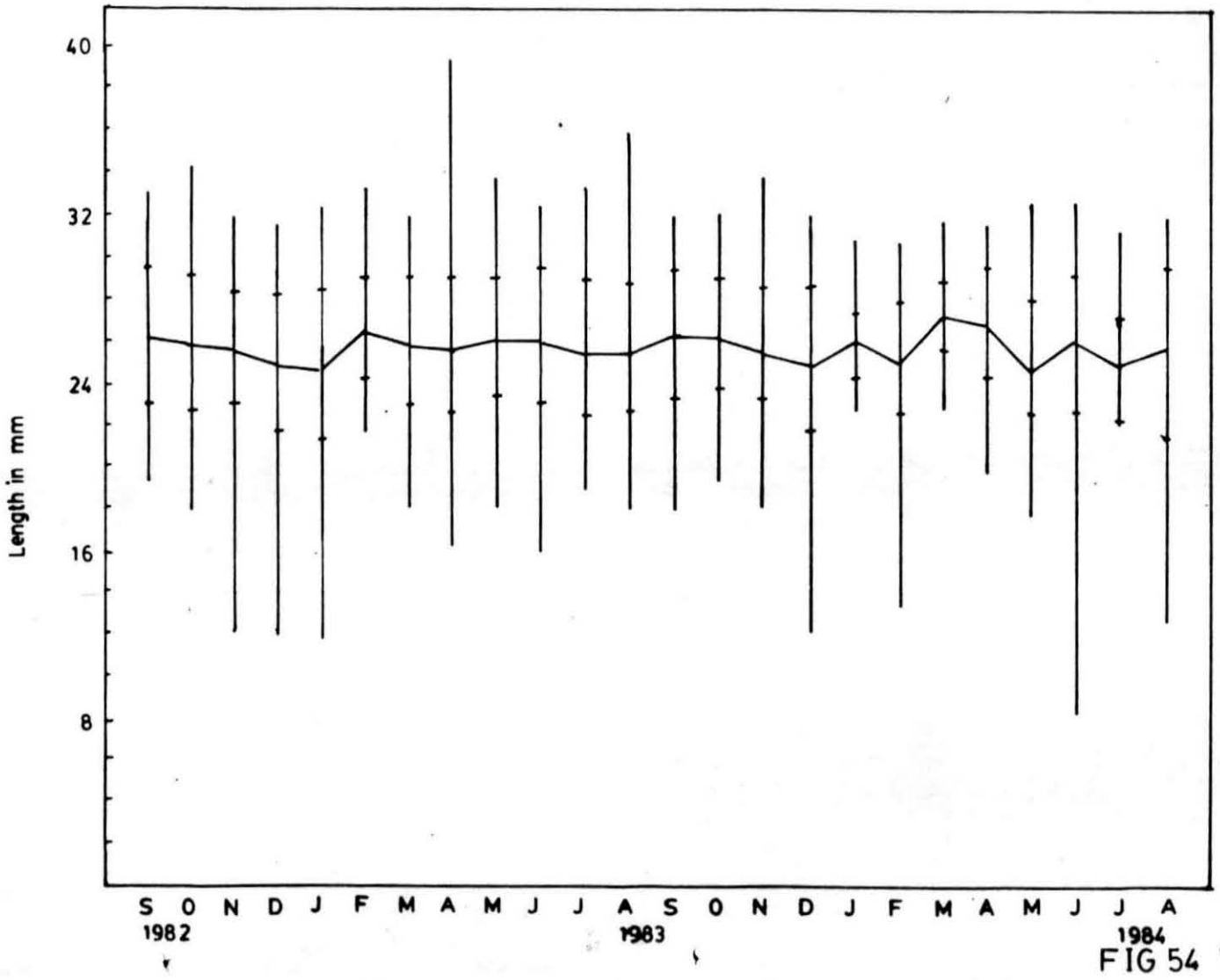

40
32
24
16
8
Length in mm
S O N D J F M A M J J A S O N D J F M A M J J A
1982
1983
1984

FIG 54

Fig. 55. Recovery (in percentage) of marked specimens of C. (C.) cingulata.

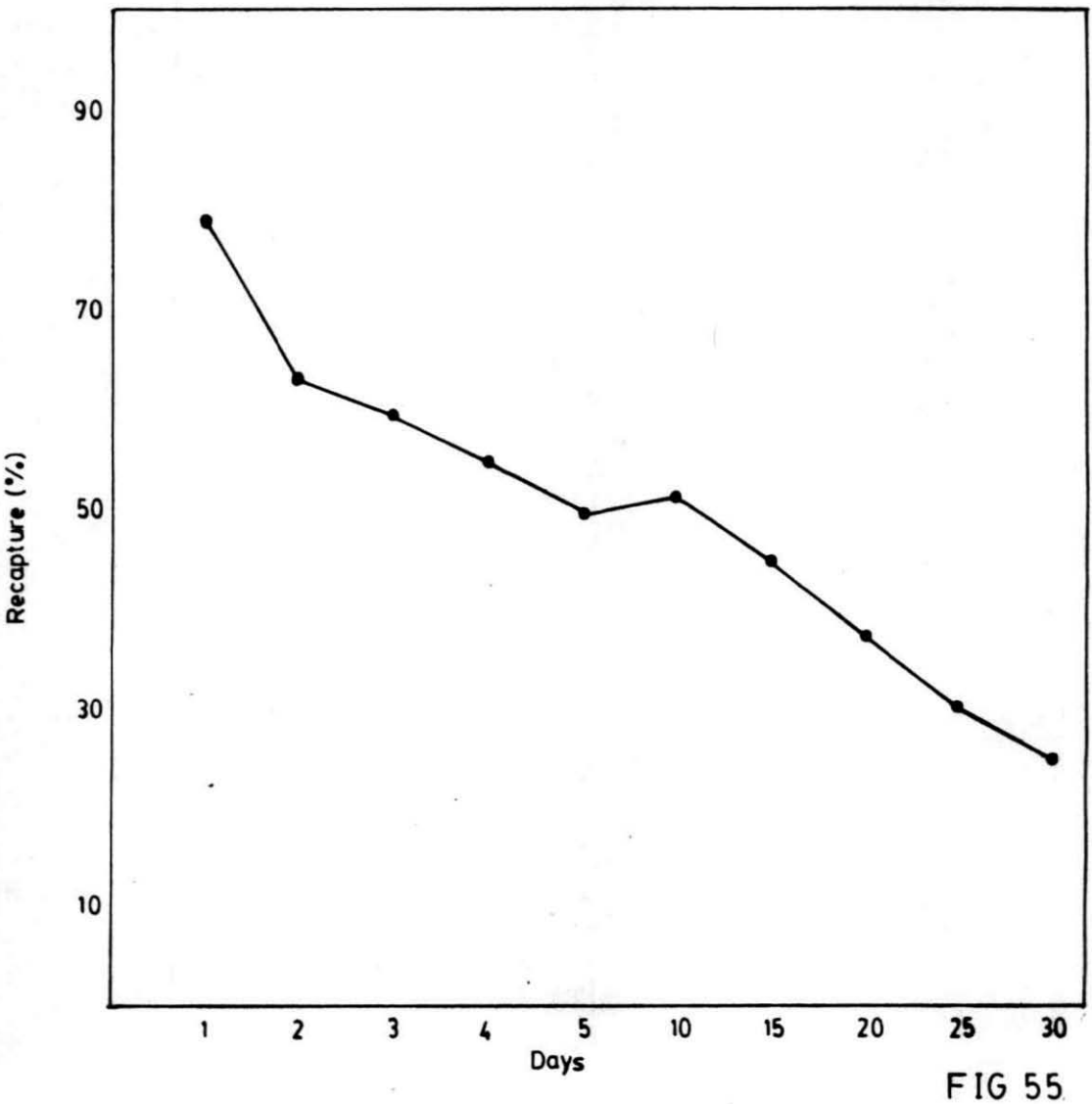


FIG 55

4. AGE AND GROWTH

4.1 INTRODUCTION

Knowledge on growth is of importance in understanding the age structure of the population, the conditions under which optimum growth is attained and the influences of various environmental factors on growth. A study of growth in tropical gastropods in general and especially of potamidids in particular, is very much needed.

Some well documented studies on growth of gastropods are those of Russel (1909) and Orton (1928a,b) on Patella vulgata, of Abe (1932) on Acmaea dorsuosa, of Rao and Raja (1936) on Trochus niloticus, of Hamai (1937) on Patelloides corulus, of Moore (1937, '38a) on Littorina littorea and Purpurea lapillus respectively, of Forbes and Crompton (1942) on Lymnaea palustris, of Graham and Fretter (1947) on Patina pallucida, of Kubo (1953) on Babylonica japonica, of Sakai (1962) on Haliotis discus, of Randal (1964) on Cittarium pica, of Williams (1964a,b, '65) on Littorina sp., Gibbula umbelicalis and Monodonta lineata, of Schalie and Davis (1965) on Oncomelania sp., of Ward (1967) on Fissurella barbedensis, of Poore (1972) on Haliotis iris, of Houbrick (1974a) on Cerithium spp.,

of Brownell et al. (1976) on Strombus gigas, of Balaparameswara Rao (1976) on Cellana radiata, of Rajagopal (1982) on Umbonium vestiarium and that of Underwood (1984) on Nerita atramentosa.

Among potamidids, age and growth studies have been carried out on Pyrazus palustris (Rao, 1938), Cerithidea (Cerithideopsilla) cingulata (Sadasivan, 1947,'48; Ramamoorthi and Alagaraja, 1969; Vohra, 1970), C. decollata (Cockcroft and Forbes, 1981a)and on C. californica (Race, 1981).

Wilbur and Owen (1964) have outlined the various methods employed for measuring growth in molluscs viz. growth rings, marked or segregated individuals, X-ray measurements, radio-isotope measurements, tetracycline as a marker and population sampling, in addition to listing the workers who used these methodologies. With an increase in body length, other parts of the shell and body parts may also show proportionate (isometric) or disproportionate (allometric) growth (Huxley and Teissier, 1936).

Presently, absolute and relative growth as well as isometric growth among body parts, as well as the allometric growth of C. (C.) cingulata have been studied since such detailed information on this species is not so far available.

4.2 MATERIAL AND METHODS

Growth of C. (C.) cingulata was estimated by three methods. Firstly, population sampling, as described by Peterson (1891) and adapted by Graham and Fretter (1947) was employed. Samples collected from all three sites for population studies, covering a period of two years from September 1982 to August 1984 were utilised for growth studies. Length of shell was measured with a vernier caliper nearest to 0.1 mm. Shells with wornout upper whorls and broken lips were rejected and normally such specimens comprised only 1% in every collection. They were sorted into various size groups (1.0 mm to 1.9 mm as 1 mm group, 2.0 to 2.9 mm as 2 mm group and so on) and percentage frequency of their occurrence was drawn for each month. The modal groups in the above figures were utilised to study growth. No sexual dimorphism could be observed externally.

The probability plot method (Harding, 1949; Cassie, 1954) of separating the polymodal length frequency distribution using a semilog paper was employed to study the age structure of C. (C.) cingulata populations.

Growth of C. (C.) cingulata was estimated by directly observing growth in the field. For this purpose, 1200 specimens, mainly of 8 mm length group (except a few 7

and 9 mm) were used, because the majority of the snails were of 8 mm length at the time of starting this study. Since numbering was not possible, the snails were painted with enamel paint of white colour on the upper half of the shells. They were released in the estuary (opposite to the Biological station) on 28.1.1983 and were remeasured on 28th of every following month. The snails were painted again with the same colour after measuring and were returned to the same site of collection. This observation was carried out for a period of 8 months (till August 1983), by which time the snails got dispersed and lost, making it difficult to trace them. Mean shell length was utilised to study the growth rates of the snails.

Morphometry of the following characters was considered for which linear measurements were taken as shown in Fig.36.

1. Length: The greatest measurement in dorso-ventral axis.
2. Maximum width: The greatest measurement of the body whorl horizontally.
3. Columellar height: Greatest measurement in dorsoventral axis from top of nuclear whorl to columellar base.
4. Height of body whorl: Greatest measurement of body whorl along dorso-ventral axis.

5. Width of oral aperture: Greatest measurement in horizontal axis from parietal to outer lip.

6. Length of oral aperture: Greatest measurement from outer lip to floor of lip.

7. Diameter of the operculum: Greatest measurement horizontally.

8. Length of hump (or Varix) of the body whorl: This hump, found only in mature snails, was measured along dorso-ventral axis.

For studying length-weight relationship, the live total weight of the snail was determined after cleaning the shell of adhering encrustations and sediment particles. The weight was taken nearest to 0.1 mg using an electrical balance. The soft parts of the snail were removed, blotted to remove the excess moisture and weighed to record the flesh weight. The sex and stage of maturity of the gonad were recorded for all measured/weighed snails.

4.3 RESULTS

4.3.1 Length frequency studies

Peterson (1891) demonstrated that multimodal length distribution of a population permitted statistical classification of the individuals into different age groups. The estimation of age and growth by using modal values in length frequency distribution has been widely employed in fishery science, where direct observations or back calculation of age based on skeletal marking are not easily observable. Basic principles of the method are: (a)length of the animals of each age group or brood are approximately normally distributed in a population, (b)growth is such that modes of the length distribution of successive age groups or broods in samples taken from the population are separated along length axis and may be readily distinguished (c)when the length frequency distribution of a sample containing a number of age groups or broods is drawn, resulting in a polymodal curve the separate modes represent approximate mean size of the constituent age groups.

In any species with extended spawning periods, mixing of various size groups tend to change the modal size. In the case of older size groups, due to the slow growth, mixing of modal sizes of different year classes is common.

In those cases, the best possible way is to trace average monthly growth rate for different stages and then to compute. From this growth curve, average size attained at different ages can be calculated.

Length frequency histograms for the two year period from September, '82 to August, '84 are given in Figs 57 & 58. A total number of 22,781 specimens were measured during the study period, ranging in size from 1.2 to 39.4 mm.

A careful perusal of data indicates that size frequency distribution was polymodal during all months because of mixing of broods of various year classes. C. (C.) cingulata spawns from February upto October in the Vellar estuary and spat settlement takes place from March to September. (vide chapter 6). Because of such prolonged breeding, survival of the larvae and growth dependupon factors like food,preferred substratum, optimum salinity and temperature etc. The spawns of certain months with ambient conditions may survive better and grow faster. Broods of such months mixed with those surveyors from adverse periods (monsoon for example) show themselves up as distinct modal groups.

When such modes are plotted separately for each month (Fig.5a), they tend to assort into year groups or year classes. Thus, in September, '82, there were two modes, one at 2 mm and another at 7 mm. Naturally these must be the products of that season and were termed brood 'C'. These modes move to 3 and 8 mm respectively in October. In November and December, '82, only the latter was represented at 8 and 9 mm, while in January, 1983 and February, '83, both groups were represented, at 9 and 11 mm respectively. In addition, during the same month, another modal group at 15 and 16 mm could also be observed, which might be the product of very early spawn of 1982. From March to July, '83, the population was unimodal and growth progressed upto 14 mm. In August, '83 two modes were seen at 15 and 21 mm. In October, '83, two modes at 13 mm and 16 mm were observed. In November and December, '83 again only one mode at 14 and 17 mm respectively was observed. Subsequently, the modes were at 17 mm in January, 1984, at 15 and 18 mm in February, '84; at 16 and 23 mm in March; at 17 and 24 mm in April; at 19 and 25 mm in May; at 20 and 24 mm in June; at 20, 23 and 25 mm in July; and at 22 and 23 mm in August, '84. Therefore, it is to be assumed that the brood 'C' of 1982 reached a

maximum size of 24 to 25 mm by August, '84. For studying probable growth, growth curves were fitted to represent a typical brood in each year giving due consideration to the rate of growth of different broods (Fig.60). From this growth curve, monthly increment in length was traced for a typical brood of each year. For the brood 'C' of 1982, the growth was from 4 mm (in September, '82) to 16 mm (in September, '83) and then to 23 mm (in August, '84) recording a net of 19 mm growth in 23 months. The actual growth however, was 12 mm during first 12 months. When the growth curve was extrapolated from 4 mm in September, '82 to 0 mm length, June (Summer) could be observed to be the approximate period of origin for brood 'C'. Therefore, from June, '82 the brood attained a size of 13 mm by June, '83 and 22 mm by June, '84, indicating a growth rate of 1.1 mm per month during the first year and 0.75 mm per month during the second year, though the growth rate was higher, at the rate of 1 mm per month in the first 6 months when the size of 19 mm was reached. From there onwards growth slowed down. It is of significance to note that though maturation of this snail could be noted in some snails of 13 mm shell length group, 50% were found to be mature at 16 mm size and 90% by 19 mm (vide chapter 6).

Diversion of energy for maturation and spawning always tend to slow down growth rates among gastropods, leading to differential growth rate between juveniles and adults (Comfort, 1957; Odum and Smalley, 1959; Feare, 1970; Cockcroft and Forbes, 1981; Shimek, 1983).

Growth curves were also drawn for brood 'B' of 1983 and 'A' of 1984. In the case of brood 'B', the growth rate was 13 mm from May, '83 to May, '84 and 16 mm by August, '84 showing a similar trend to that of 'C'. For brood 'A' the growth rate was 7 mm in 5 months from April to August, '84. It is interesting to note that June was the origin of the typical brood in 1982, May in 1983 and April, in 1984, all of which are typical summer months offering more stable conditions for the settlement of the brood. This is further confirmed by the fact that largest numbers of veliger larvae of C.(C)cingulata were observed only during these summer months.

A significant feature observed in 1983 year class was that it was unimodal during most of the period, indicating the emergence of brood settled at one particular period, when conditions were favourable. It can also be inferred that unfavourable conditions might have prevailed during rest of the breeding period of that year preventing

the emergence of any other broods. This probably resulted in poor recruitment to 1983 year-class, and it could be recorded only in very low percentage in subsequent year, i.e., 1984. On the otherhand, the brood 'C' of 1982 was observed to go strong even in 1984. It may be of relevent here to mention that 1982 was a severe drought year for whole of Tamil Nadu. Such drought years were observed to result in poor recruitment to shrimp population in Casamanca estuary, Senegal (Marius, 1976; Le Reste, 1980). Marius (1976) stated that the effect of a hard dry season could be felt on the shrimp populations for several subsequent years. Le Reste (1980) found a correlation between the rainfall of a particular year and catches of shrimps in the subsequent years and recorded that years of low rainfall were always followed by poor catches. While favourable monsoon seasons tend to create ideal conditions for higher recruitment of various populations, adverse monsoon seasons appear to result in uncongenial conditions such as closure of bar mouth, low mixing, less flushing and poor replenishment of nutrients from land run off, which result in poor recruitment.

Though the growth of younger broods could be traced, it was difficult in the case of older size groups. Slow growth rate and mixing of successive year classes tend to make growth estimations erroneus. However, assorting of

modal groups helped in tracing the growth. Taking into consideration the brood 'C' the modal groups at 17 and 21 mm (in August) can safely be assumed as the spawn of 1981 (labelled as brood 'D'). Subsequently, the modes shifted to 19 mm in November, 21 mm in December, 24 mm in January, 1983, 22 mm in February, 23 mm in March, 23 and 24 mm in April and May, 23 and 26 mm in June, 27 and 28 mm in July, August and September, 27 and 28 mm in January, 1984, 28 mm in March, April and May and 28 and 30 mm in June, July and August, '84. Growth curve indicated a growth of 7 mm (from 19 to 26 mm) in the first 12 months and of 4 mm (from 26 to 30 mm) in the second 11 months, with a growth rate of 0.58 and 0.36 mm per month respectively. The brood with a modal size of 19 mm at September in the subsequent year (1982), might have originated during March, 1981 attaining a size of 22 mm at the end of second year progressing to 28 mm by the end of the third year and to 30 mm by 41 months. The growth pattern of 'D' is thus observed to be similar to that of 'C' during the second year of life.

Two more broods (E and F) were also discernible during September/October 1982. The former appeared to be the product of 1980 and the latter that of 1979. Brood 'E'

could be traced almost for one year, while 'F' was recorded only in October and November 1982. Brood 'E' showed a growth rate of 5 mm (from 26 mm to 31 mm from September 1982 to next September) after which it could not be traced.

By comparing the growth rates of broods A to F, a growth curve was drawn for C. (C.) cingulata (Fig. 61), which was sigmoid. Estimation of the growth was 13 mm at the end of first year, 22 mm at the end of the second, 28 mm at the end of third and 32 mm by the end of fourth year, the net growth being 13, 9, 6 and 4 mm respectively. The rate of growth was 1.08 mm during the first year, 0.75 mm in the second year, 0.50 mm in the third year and 0.33 mm in the fourth year. Because of differences in the month of origin of a brood during each year, the modal size group of each brood is found to vary during different months. The life span of C. (C.) cingulata appears to be four years under normal circumstances. From an analysis of the data, it is evident that relative growth slowed down after the first year upto fourth year, showing an inverse relationship with actual growth.

4.3.2 Probability plot method

Estimation of growth by this method is advantageous for species with prolonged spawning season. Certain year classes not represented in samples collected and overlapping of distribution of older size groups often tend to influence the estimation of age by Peterson's method. Some of these errors are minimised, if this method is employed, since composition of various size groups during the whole year can be utilised here.

Growth curves were plotted separately for 1982-'83 and 1983-'84 (Fig.62). Based on the data for 1982-'83, the estimated rate of growth was 9.5, 18.5, 16.75 and 32.25 mm at the end of I, II, III and IV years respectively. The actual growth was 9.5 mm during the first year, 9 mm in the second year, 8.25 mm in the third year and 5.5 mm in fourth year, with a growth rate of 0.8, 0.75, 0.69 and 0.46 mm respectively. Growth curve for 1983-'84 also showed that the growth was 9.75 mm in the first year, 19.0 mm in the second year, 26.5 mm in the third year and 30.5 mm in the fourth year. The relative growth was 9.75 mm in the first year, 9.25 mm in the second year, 7.5 mm in the third year and 4 mm in the fourth year, with a growth rate of 0.81, 0.77, 0.63 and 0.33 mm respectively. Altogether, the

estimated growth may be recorded as 9.62, 18.75, 26.62 and 31.37 mm, the relative growth was 9.62, 9.13, 7.87 and 4.75 mm and the rate of growth was 0.8, 0.76, 0.65 and 0.4 mm respectively. Estimated growth from the probability plot method showed slight difference from population sampling during the first two years, but was found to be similar during the next two years.

4.3.3 Marking and recovery

Results on the growth rate studies of C. (C.) cingulata, from marking and recovery experiments, are given in Fig.63, wherein the length range, number of animals measured and the mean size are indicated. At the beginning of the study in January 1983, the snails ranged between 7 and 9 mm shell length and this was observed to increase to 11 and 17 mm in June, indicating differential growth between individuals. However, the mean increment in length was gradual from an initial mean length of 8.2 mm in January to 9.6 mm in February, 10.8 mm in March, 12.0 mm in April, 13.1 mm in May, 14.2 mm in June, 14.9 mm in July and 15.5 mm in August. Taking into consideration the growth rate observed from January to June (since the samples in July and August

were meagre), the actual increment was 6 mm in five months (from 8.2 to 14.2 mm) at the rate of 1.2 mm per month. It is of significance that the growth estimated from population sampling method was similar to the present one.

4.3.4 Growth parameters

Growth parameters such as the maximum size attained (L_∞), the katabolic coefficient (K) and the arbitrary origin of growth curve (t_o) were estimated for C. (C.) cingulata. While the asymptotic length L_∞ can be obtained both by Walford graph and von Bertalanffy's equation, the other parameters have to be deduced from the latter equation only.

(a) Walford graph

A geometric interpretation of the pattern of growth in length was developed by Walford (1946). This method is based on the assumption that successive increment added to length at definite time intervals, decrease in geometric progression, till a limiting value of total length, ultimate length or length at infinity (L_∞) is approached. Walford graph was constructed for C. (C.) cingulata (Fig.64) by

plotting Lt + 1 against Lt, where the Lt is the length of the animal at a particular age. From the straight line obtained by connecting the maximum points from the Lt + 1 against Lt graph, on intersecting by 45° diagonal from the origin, the L ∞ value was found to be 42.0 mm. Maximum size of the snail collected during the period of observation was 39.4 mm (the largest size so far known for this species) which is fairly close to the L ∞ obtained.

(b) von Bertalanffy's equation

von Bertalanffy's growth equation is a decaying exponential that has been used to study growth in a variety of forms (von Bertalanffy, 1938; Beverton and Holt, 1957). The mathematical expressions are helpful in interpolation and extrapolation and also in production computation (Pantulu, 1963). Since growth is the net result of anabolism and katabolism, a growth curve fits well with the growth rate of many species (Beverton, 1954; Beverton and Holt, 1957). This equation gives a linear relationship between lengths, at time 't' and t+ and is expressed as:

$$Lt = L\infty \left[1 - e^{-k(t-t_o)}\right]$$

where Lt = Length at age 't'

L_∞ = asymptotic length attained

e = base of natural logrithms

k = coefficient of katabolism

t = age of the animal

t_o = arbitrary origin of the growth curve

The age structure obtained by length frequency method and marking experiments are very much similar and so the age and corresponding length of C. (C.) cingulata, obtained from length frequency method, was utilised for calculations. The various parameters obtained are:

L_∞ = 39.99

k = 0.4054

t_o = 0.0977

von Bertalanffy's growth equation for C. (C.) cingulata is

$$L_t = 39.99 \left[1 - e^{-0.4051\ (t\ -0.0971)}\right]$$

The theoretical growth curve obtained for this species is given in Fig.65, and both calculated and observed values were very close to each other.

4.3.5 Dimensional relationship of shell and operculum

To study the increments in other shell dimensions and in the operculum, in relation to shell length, the simple linear regression equation

$$y = a + bx$$

where x is equal to the length, y the variable, a and b constants, was employed.

The results obtained for seven variables, like maximum width, columellar length, length of oral operture, width of oral operture, length of body whorl, diameter of operculum and length of hump on the body whorl are given in Table 14 and the regression lines in Fig.66. All the values are highly significant at 0.01% level and the correlation coefficient (r) very close to 1. The relationship is always linear indicating that the variables always grow in proportion to shell length, in smaller to larger individuals. These morphometric relationships can hence be termed isometric in the case of C. (C.) cingulata. Of the seven variables, least growth could be recorded in the case of operculum while maximum increase was observed in the case of columellar length.

4.3.6 Length-weight relationship

Length-weight relationship study helps (1)in establishing a mutual relationship between variables, (2)to know the condition or well being of the animal and (3)to understand the relationship between variations in expected weights from juveniles to adults. Le Cren (1951) found that weight of a fish is a linear function of length and length-weight relationship always obeys the hypothetical cube law

$$W = C\ L^3$$

where W is weight, L, length and C a constant. As most animals change their form or shape with growth (Mortin, 1949) the formula can be rewritten as

$$W = b\ L^3 \qquad \text{or} \qquad W = a\ L^n$$

where W and L are weight and length respectively, and b or a constants equivalent to C and n is another constant to be calculated from the data. The constant 'n' represents relative increase in weight compared to length. However, significant variations in n (3) is found to be rare (Beverton and Holt, 1957), and for organisms which maintain their shape throughout, without change, the value of b will always be 3 (Allen, 1938). But the value of observed W was found to be between 2.5 and 4.0 (Hile, 1936; Martin, 1949) and

even 1.37 in the case of Teredo sp. (Isham et al.

The general equation $w = a L^n$ can be written $\log w = \log a + n \log l$, i.e., $y = a + b X$ which is a linear relationship between y and X. This linear equation helps to calculate the relationship between length and total weight and between length and flesh weight. Males, females and juveniles were separated in order to know the possible variations on attaining maturity. The regression lines for total weight and length are given in Fig.67 A and that for flesh weight and length in Fig.67 B. They revealed highly significant correlation at 0.01% confidence limit, as the 'r' values were close to 1 (Tables 15 and 16).

The data were subjected to analysis of covariance (Snedecor, 1955) and the details for length and total weight and length and flesh weight are given in Tables 17 and 18 respectively. It may be seen from the tables that mature males and females did not differ significantly from each other but differed from juveniles in case of total weight as well as of flesh weight, in relation to length. Hence common equations for males and females were derived as follows:

Total weight : $\log w = -0.6646 + 2.6575 \log l$

Flesh weight : $\log w = -1.6383 + 2.7151 \log l$

The equations for juveniles are as follows:

Total weight : $\log w = -0.0106 + 1.9646 \log l$

Flesh weight : $\log w = -2.3215 + 3.2525 \log l$

4.3.7 Age composition of the population

The length composition of C. (C.) cingulata during the years 1982-'83 and 1983-'84, is presented in Fig.68, which evidences the fact that the population was a mixed one of different ages. In 1982-'83, the maximum contribution was by 8 and 10 mm shell length individuals while in 1983-'84 16 mm was predominant. Evidently the former belongs to 0-year class (less than a year) and the latter is one year old (or 1-year class). This may be due to poor recruitment to the population during 1983-'84 as indicated already in an earlier observation. However, when percentage contribution by different length groups of the same year class is combined together, it was observed that 0-year class was always dominant over others (Fig.69). The contribution by 0-year class in 1982-'83 was 75.5% but it was only 51.5% in 1983-'84. This again evidences the poor entry of new broods to the population during 1983-'84.

There is also a gradual decline in the percentage

contribution by various year classes in subsequent years. Thus, the 0-year class of 1982-'83 declined from 75.5 to 37.3% in 1983-'84; 1-year class of 1982-'83 from 16.2 to 10.1% in the next year; 2-year class of 1982-'83 from 7.0 to 1.3%, while 3-year class was either negligible or totally disappeared in the subsequent year.

4.4 DISCUSSION

Regarding C. (C.) cingulata, observations by Sadasivan (1947) indicated that growth was faster in younger snails, which attained 10 mm shell length size within 7 months, based on field observations and laboratory rearing. He estimated a growth of 22 mm in 19 months and 26 mm in 36 months in Adyar estuary (southeast coast of India near Madras city). On the maximum size of the specimens of C. (C.) cingulata, he stated that only a few shells of 26 mm and exceptionally 30 mm shell length sizes could be collected. He attributed this to the very slow or reduced growth rate after 22 mm when the snail attained maturity. Based on his observations, he also suggested that the longivity of the snail as around 5½ years.

Ramamoorthi and Alagaraja (1969), based on their preliminary observations on C. (C.) cingulata in the Vellar estuary, concluded that this snail grew 1 mm in each month in younger stages.

Vohra (1970), who studied populations of C. (C.) cingulata in Singapore beach, observed a growth of 8 mm in 12 months. He also stated that growth was fast upto 1.35 mm during the first 6 months, 0.95 mm in the next three months and 0.6 mm in the last three months. He recorded 17 mm as the largest size in the population.

The present observations showed similar results to that of Ramamoorthi and Alagaraja (1969) in that growth was 1 mm during each month in younger snails but differed slightly from the estimates of Sadasivan (1947) and Vohra (1970) - in that growth was slower than that of Madras population and more than that of Singapore population. Moreover, in the present observation, the rate of growth was more and steady upto 18th month when the animal reached the length of 19 mm, and slowed down thereafter. Sadasivan (1947) reported faster growth upto 22 mm but a very slow growth thereafter, while Vohra (1970) reported faster growth rate for the first six months, becoming slow thereafter. Snails with a shell length of 39.4 mm could be

recorded in the present study but not in previous observations, C (C.) cingulata seems to exhibit differences in growth rate in various localities, depending upon environmental conditions.

The estimated longevity of four years for C. (C.) cingulata under normal conditions was not uncommon among gastropods. Comfort (1957) estimated the longevity for a number of gastropods and found it to range from 1 to 20 years. Poore (1972) estimated a longevity of 10 years for Haliotis iris. Balaparameswara Rao (1976) found the longevity of Cellana radiata to be around 5 years. Cockcroft and Forbes (1981a) estimated the longevity of Cerithidea decollata to be in excess of 9 years. Therefore, it is obvious that longevity varies markedly between species to species. The estimated longevity of C. (C.) cingulata falls well within the above ranges mentioned by others.

A variety of factors are known to affect the rate of growth and the ultimate size reached by intertidal gastropods. Many workers have ascribed irregular growth to the availability of food. Moore (1938b) showed that in the case of Purpurea lapilus, differences in relative availability of food affected growth. Underwood (1984) showed positive correlation between chlorophyll in the

substratum and the rate of growth in Nerita atramentosa, indicating availability of food as a major factor for growth. The relatively vigorous growth in C. (C.) cingulata indicates that there is no dearth of food supply in the environment in which it lives.

Growth was found to be much faster during summer and slow or absent in winter in temperate waters in general (Russel, 1909; Graham and Fretter, 1947; Vohra, 1970; Poore, 1972; Cockcroft and Forbes, 1981a). It has already been well established that in tropical waters, the animals are subjected to high temperature and show increased initial growth, precocious maturity and intense spawning (Neylor, 1965). Observations by Balaparameswara Rao (1976) on Cellana radiata, by Manmadha Rao (1977) on Clypeomorus sp. and by Rajagopal (1982) on Umbonium vestiarium indicate no seasonal variations in the growth pattern. In C. (C.) cingulata also there is no seasonal variations in growth rate as evidenced by earlier workers (Sadasivan, 1947; Ramamoorthi and Alagaraja, 1969) and also by the present study.

Sadasivan (1947) found no growth in C. (C.) cingulata in freshwater conditions. According to Arnold (1957) the growth and survival of an animal is affected

only in salinities in which the animal cannot feed or search for food. Such a conditions for C. (C.) cingulata seems to occur only in a salinity range of 0-5‰, though it subsists for a prolonged period (vide Chapter 3.2).

Forbes and Crompton (1942) found that larger the number in the compound aggregation, the smaller the size, in the case of Lymnaea palustris. Schalie and Davis (1965) observed greater mortality, stunting and suppression of sexual maturity in cultured samples of Oncomelania sp. Reduced density of population was observed to induce higher rate of growth by Sutherland (1970) and Haven (1977) in the case of Acmaea scabra; by Underwood (1976) in the case of Nerita atramentosa and by Creese (1980) on Notacmaea petterdi. Overcrowding results in accumulation of metabolic wastes, decreased food supply and greater scope for infection, all of which invariably affect the population. However, in an open estuary where ample space is available and where the tidal flushing replenishes the water and brings more food materials, the effect of overcrowding may be minimal.

The relative growth of the body parts in relation to shell length is gradual and isometric. The shell becomes broader when length, breadth and width of the oral aperture are increased, the height of the body whorl and the hump on

the body whorl and the operculum increase in size proportionately to the length of the shell. In this aspect, C. (C.) cingulata resembles Cellana radiata (Balaparameswara Rao, 1976) and Clypeomorus sp. (Manmadha Rao, 1977).

On the otherhand, an allometric relationship was found in length-weight relationship, between juveniles and adults, both in the case of total weight and flesh weight. This variation could be attributed to sexual maturity, but may also be due to increase in size as observed by George John (1980) in the case of Anadara rhombea.

Salient findings of the present study can be summarised as follows:

1. Employing Peterson's method, the growth of C. (C.) cingulata estimated was 13, 22, 28 and 32 mm in the first, second, third and fourth year respectively. The actual growth was 13 mm (at the rate of 1.08 mm per month), 9 mm (0.75 mm/month), 6 mm (0.5 mm/month) and 4 mm (0.33 mm/month) during the four year period.

2. Slowing down of growth rate was noticed from 19 mm onwards probably due to attainment of maturity and subsequent breeding activity.

3. Growth estimated by probability plot method was 9.5 to 9.75 mm in 1-year, 18.5 to 19.0 mm in

2-year, 26.5 to 26.75 mm in 3-year and 30.5 to 32.25 mm in 4-year.

4. Growth observed by marking experiments was 6 mm in 5 months.

5. Walford graph gives an asymptotic length of 42 mm for C. (C.) cingulata.

6. von Bertalanffy's growth equation for estimating the Lt at the age of t is:

$$Lt = 39.99 - \left[1^{-e^{-0.4054(t - 0.0971)}}\right]$$

7. Morphometric studies indicated that growth of various body parts in relation to length was linear and isometric.

8. Length-weight relationship of both total and flesh weight varied between juveniles and adults and therefore two equations have been derived separately.

Total weight:

Juveniles	:	-0.0106 + 1.9646 log l
Adults	:	-0.6646 + 2.6575 log l

Flesh weight:

Juveniles	:	-2.3215 + 3.2525 log l
Adults	:	-1.6383 + 2.7151 log l

9. Population was composed of 0-, 1-, 2-, and 3-year classes mainly, of which 0-year class was dominant.

10. There was no apparent limiting influence of environmental

factors such as food, season, salinity and overcrowding on the growth of C. (C.) cingulata in the Vellar estuary.

Table 14. Morphometric relationship between body parts on shell length in C. (C.) cingulata.

Sl. No.	Characters	n	b	a	r	p	Significant at
1.	Width	128	0.3113	0.8405	0.9841	0.001	0.1%
2.	Columellar length	128	0.9628	-0.2743	0.9990	0.001	0.1%
3.	Length of oral aperture	128	0.2797	0.3196	0.9823	0.001	0.1%
4.	Width of oral aperture	128	0.1864	0.3686	0.9792	0.001	0.1%
5.	Length of body whorl	128	0.2673	1.6964	0.9812	0.001	0.1%
6.	Diameter of operculum	128	0.1367	0.0017	0.9834	0.001	0.1%
7.	Length of hump on the body whorl	55	0.1371	1.3629	0.8591	0.001	0.1%

n = number of specimens

a & b = constants

r = correlation coefficient

p = level of significance

Table 15. Length-total weight relationship in C. (C.) cingulata.

Sl. No.	Groups	n	b	a	r	p	Significant at
1.	Juvenile	64	1.9646	-0.0106	0.8025	0.001	1%
2.	Male	67	2.6937	-0.7024	0.9847	0.001	1%
3.	Female	59	2.6334	-0.6272	0.9812	0.001	1%

Table 16. Length-flesh weight relationship in C. (C.) cingulata.

Sl. No.	Groups	n	b	a	r	p	Significant at
1.	Juvenile	55	3.2525	-2.3215	0.9656	0.001	0.1%
2.	Male	67	2.8309	-1.7645	0.9182	0.001	0.1%
3.	Female	59	2.6770	-1.6203	0.8820	0.001	0.1%

n = number; a & b = constants; r = correlation coefficient; p = level of significance

Table 17. Regression of log total weight on log length in C. (C.) cingulata (testing the equality of the regression coefficient 'b' between juvenile, male and female).

Group	DF	sx^2	sy^2	sxy	DF	s.s.
Juvenile	63	2.6812	16.0712	5.2676	62	5.7222
Male	66	0.5629	3.9438	1.4196	65	0.1190
Female	58	0.6377	4.5938	1.6795	57	0.1705
					184	6.0117
Within groups	187	3.8458	24.6088	8.3667	186	6.4067

Variations due to	DF	s.s.	m.s.	F	F ratio 5%-1%	Significant at
Combined						
Between groups	2	0.3950	0.1975	6.04	3.04-4.71	1-5%
Within groups	184	6.0117	0.0327			
Between juvenile and male						
Between groups	1	0.2345	0.2345	5.10	3.92-6.84	5%
Within groups	127	5.8412	0.0460			
Between juvenile and female						
Between groups	1	0.2307	0.2307	4.66	3.92-6.84	5%
Within groups	119	5.8927	0.0495			
Between male and female						
Between groups	1	0.0011	0.0011	2.18	3.92-6.84	Not significant
Within groups	122	0.2895	0.0024			

Table 18. Regression of log flesh weight on log length in C. (C.) cingulata (testing the equality of regression coefficient 'b' between juvenile, male and female).

Group	DF	sx^2	sy^2	sxy	DF	s.s.
Juvenile	54	1.3841	15.7048	4.5017	53	1.0633
Male	66	0.5272	5.0149	1.4924	65	0.7902
Female	58	0.6377	5.8752	1.7074	57	1.3037
					175	3.1572
Within groups	178	2.5490	26.5949	7.7015	177	3.3257

Variations due to	DF	s.s.	m.s.	F	F ratio 5%-1%	Significant at
Combined						
Between groups	2	0.1685	0.0843	4.66	3.06-4.75	1%
Within groups	175	3.1572	0.0181			
Between juvenile and male						
Between groups	1	0.0679	0.0679	4.32	3.92-6.84	5%
Within groups	118	1.8535	0.0157			
Between juvenile and female						
Between groups	1	0.1444	0.1444	6.72	3.92-6.84	5%
Within groups	110	2.3670	0.0215			
Between male and female						
Between groups	1	0.0068	0.0068	2.53	3.92-6.84	Not significant
Within groups	122	2.0939	0.0172			

Fig. 56. Measurements employed for morphometric characters of C. (C.) cingulata.

CH : Columellar height

DO : Diameter of operculum

L : Length

LBW: Length of body whorl

LHBW: Length of hump on body whorl

LOA: Length of oral aperture

MW : Maximum width

WOA: Width of oral aperture

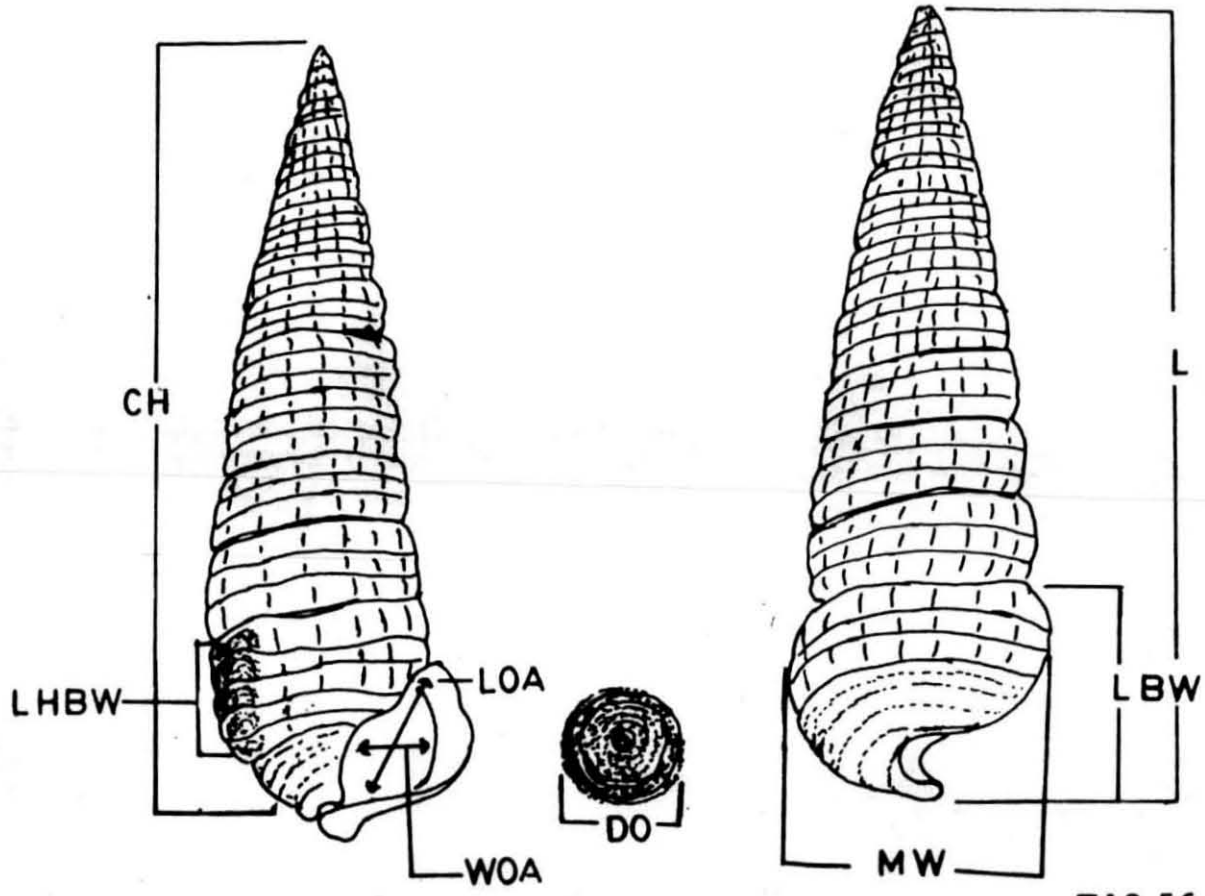


FIG 56

Fig. 57. Length frequency of the population of C. (C.) cingulata during 1982-'83 (n : number of specimens examined).

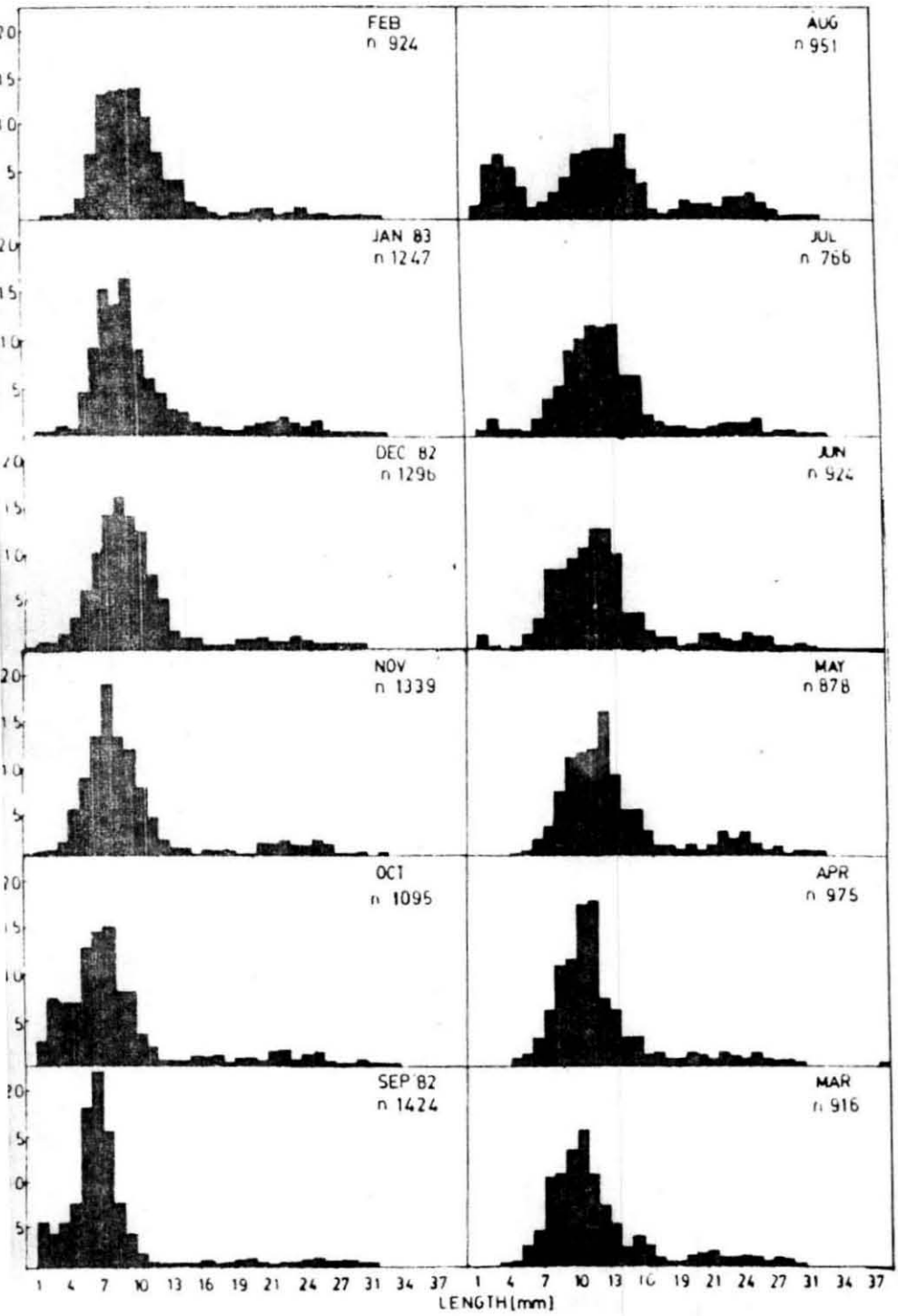

FEB
n 924
AUG
n 951
JAN 83
n 1247
JUL
n 766
DEC 82
n 1296
JUN
n 924
NOV
n 1339
MAY
n 878
OCT
n 1095
APR
n 975
SEP 82
n 1424
MAR
n 916
1 4 7 10 13 16 19 21 24 27 31 34 37
LENGTH (mm)

FIG 57

Fig. 58. Length frequency of the population of C. (C.) cingulata during 1983-'84 (n . number of specimens examined).

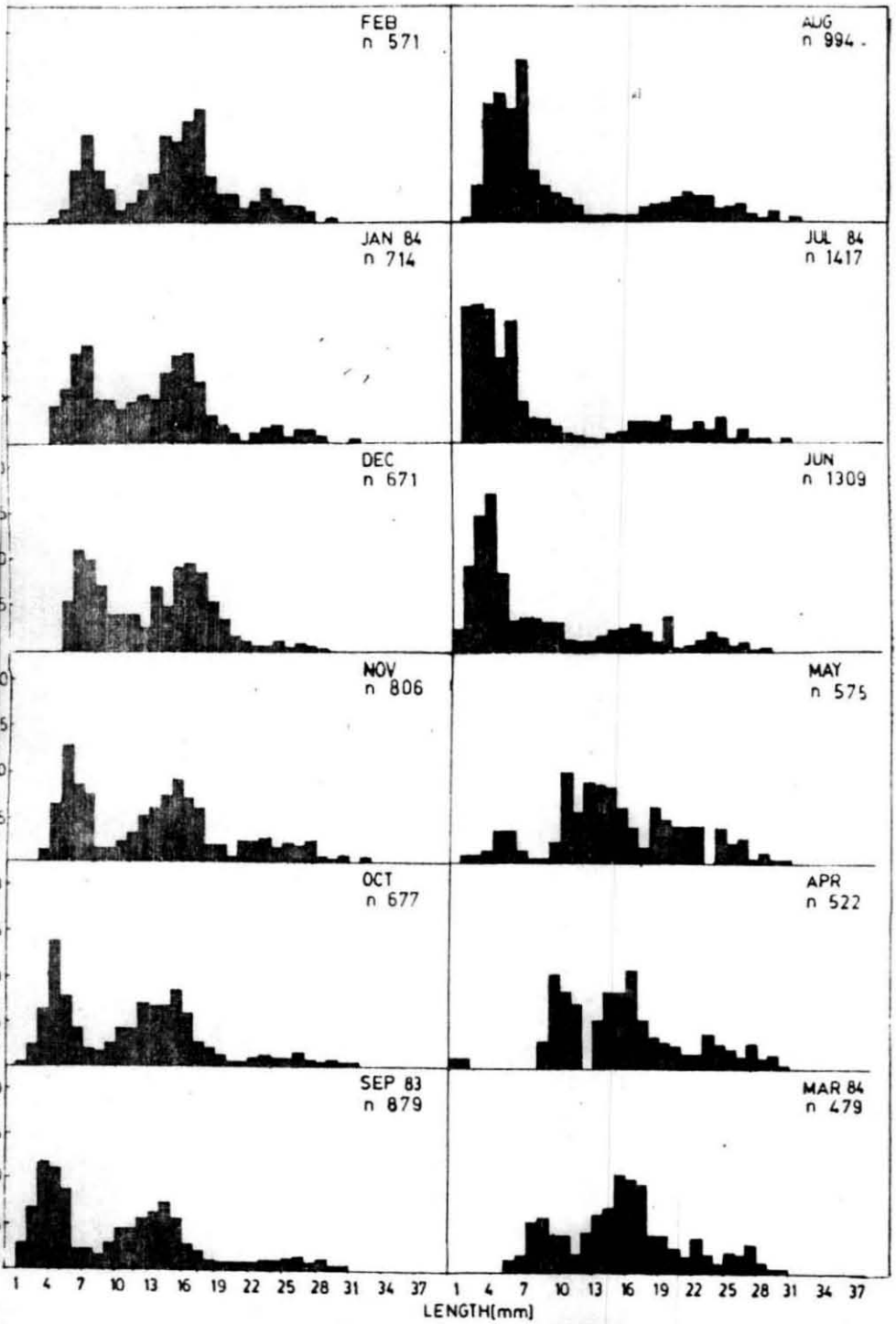

FEB
n 571
AUG
n 994
JAN 84
n 714
JUL 84
n 1417
DEC
n 671
JUN
n 1309
NOV
n 806
MAY
n 575
OCT
n 677
APR
n 522
SEP 83
n 879
MAR 84
n 479
1 4 7 10 13 16 19 22 25 28 31 34 37
1 4 7 10 13 16 19 22 25 28 31 34 37
LENGTH(mm)

FIG 58

Fig. 59. Modal values of broods of C. (C.) cingulata (A to F) in different months.

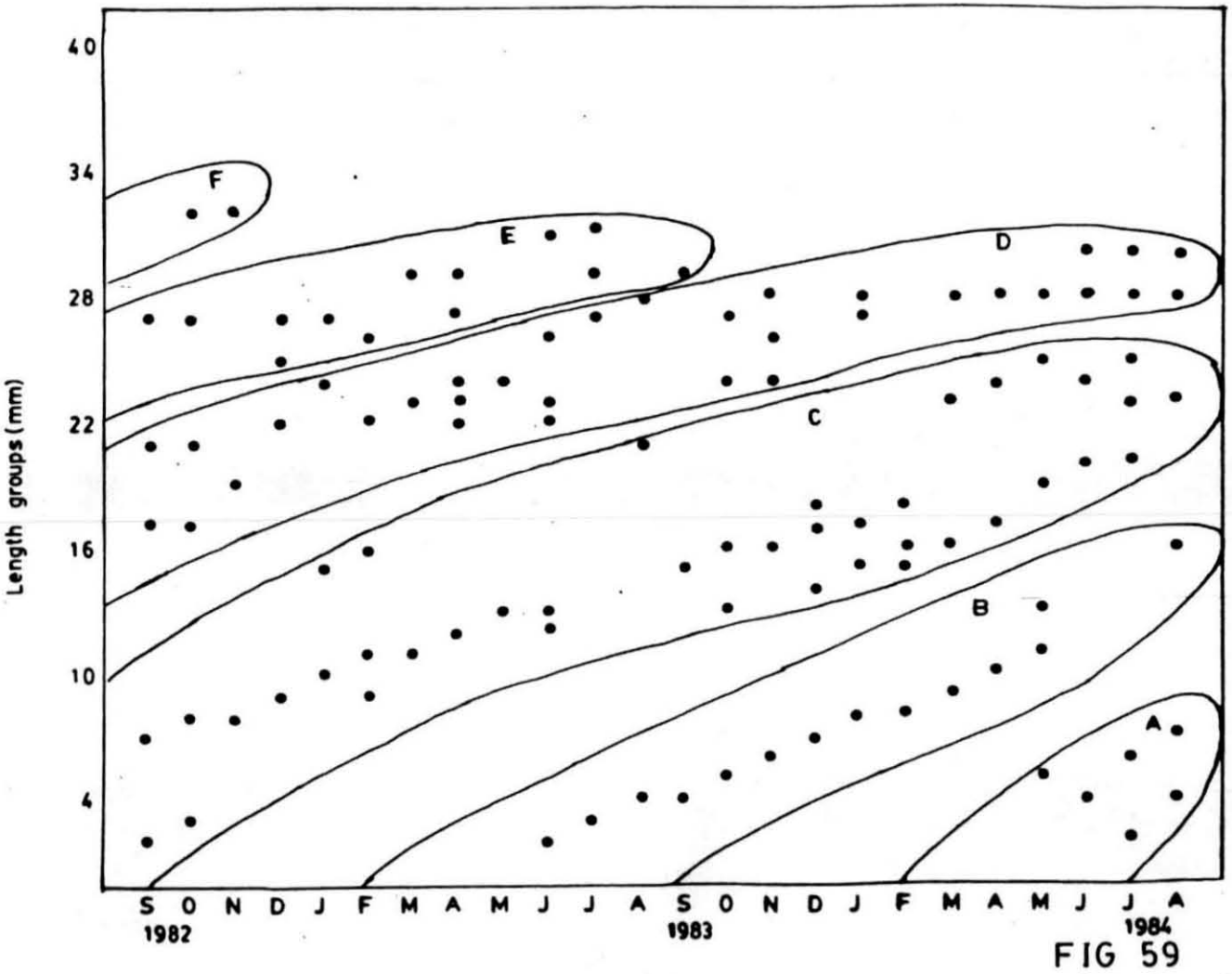

40
34
28
22
16
10
4
Length groups (mm)
F
E
D
C
B
A
S O N D J F M A M J J A S O N D J F M A M J J A
1982
1983
1984

FIG 59

Fig. 60.Growth curves of the broods of C. (C.) cingulata

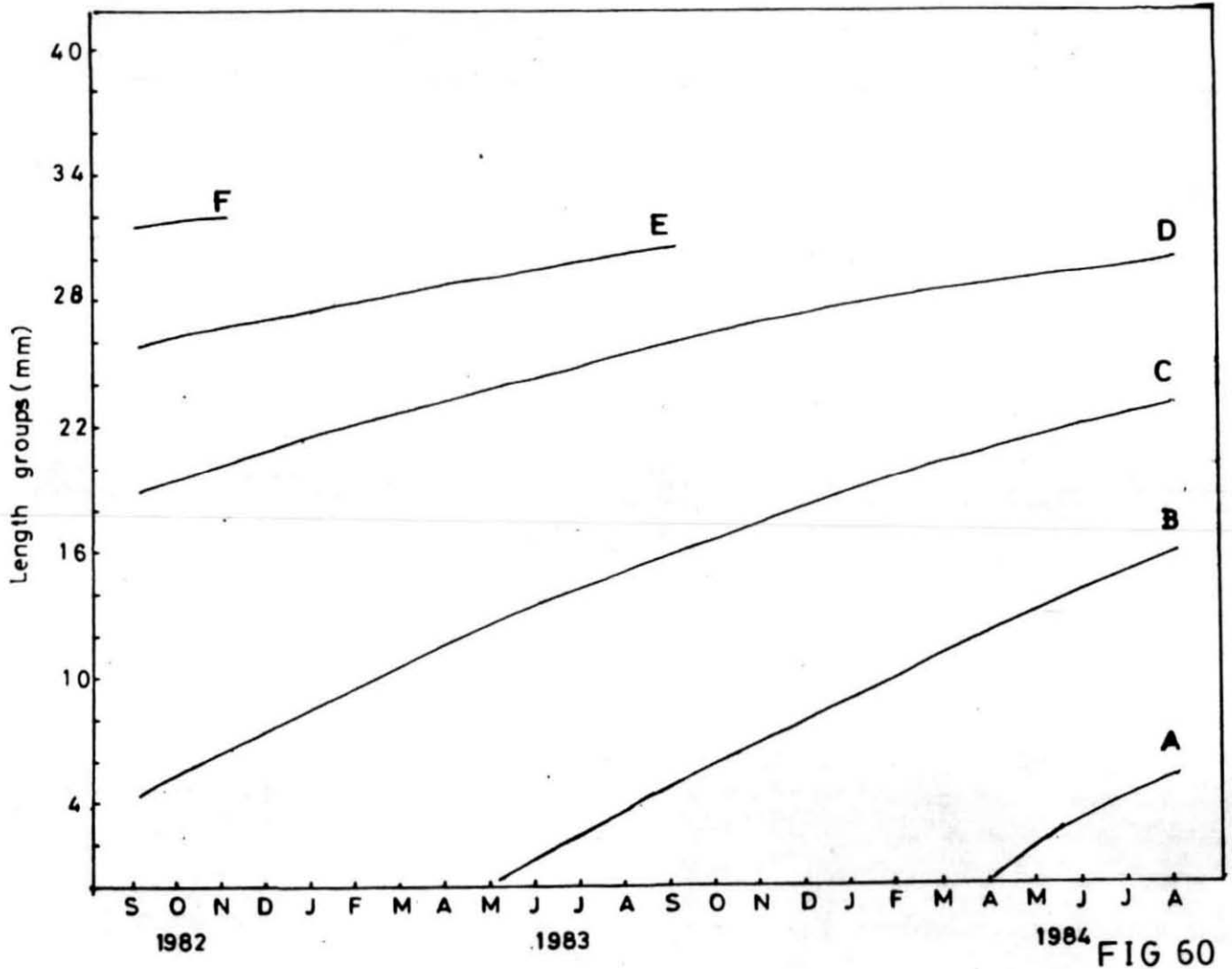

40
34
28
22
16
10
4
Length groups (mm)
F
E
D
C
B
A
S O N D J F M A M J J A S O N D J F M A M J J A
1982
1983
1984

FIG 60

Fig. 61. Growth curve of C. (C.) cingulata. (Net growth in each year of life is given in the inset)

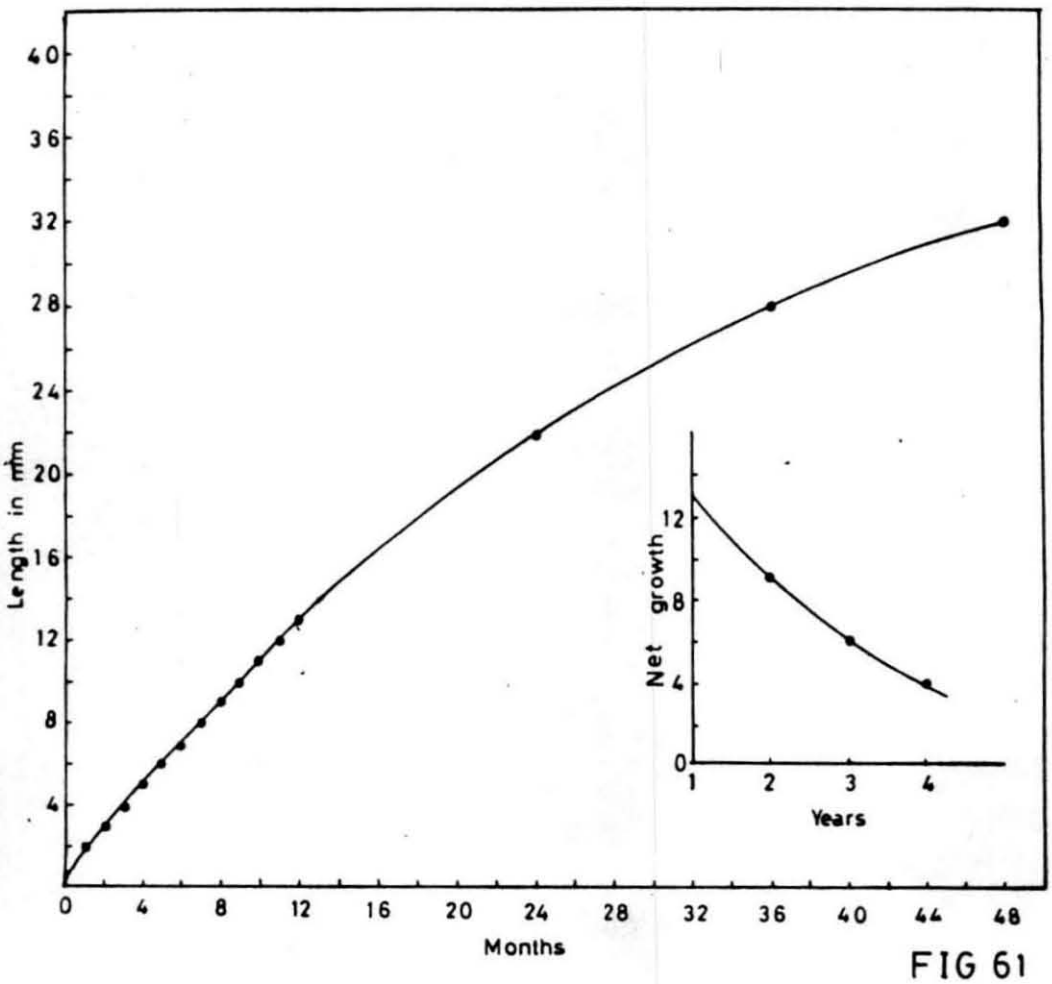
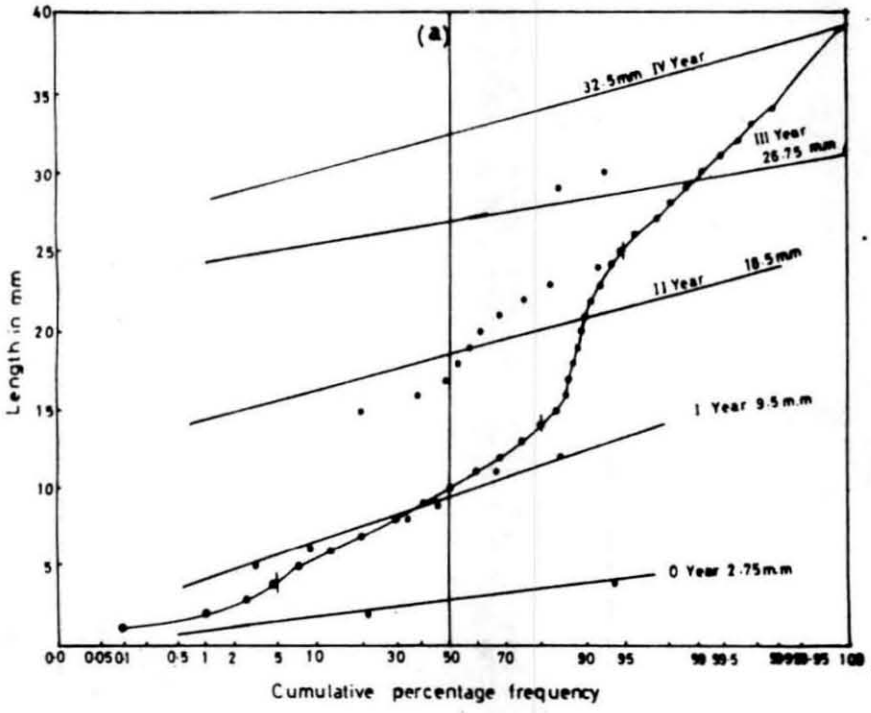

Length in mm
40
36
32
28
24
20
16
12
8
4
0
4
8
12
16
20
24
28
32
36
40
44
48
Months
Net growth
12
8
4
0
1
2
3
4
Years

FIG 61

Fig. 62. Growth curve of C. (C.) cingulata obtained by probablity plot method (a : 1982-'83; b : 1983-'84)


(a)
32·5mm IV Year
III Year
26·75 mm
II Year 18·5mm
I Year 9·5 m.m
0 Year 2·75m.m
Length in mm
Cumulative percentage frequency

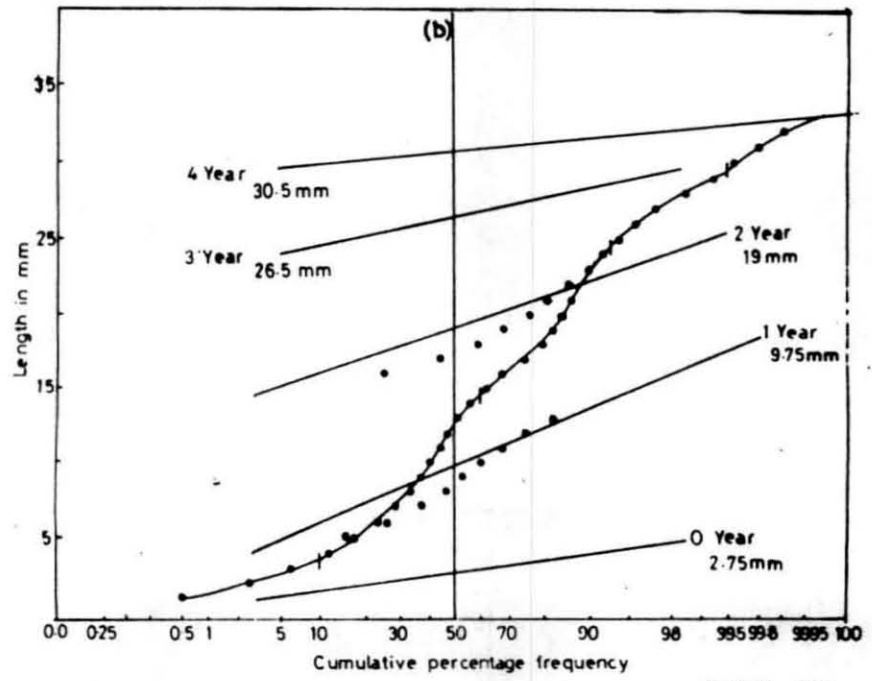

(b)
4 Year
30·5mm
3 Year
26·5 mm
2 Year
19mm
1 Year
9·75mm
0 Year
2·75mm
Length in mm
Cumulative percentage frequency

FIG 62

Fig. 63. Length frequency of marked and recovered specimens of C. (C.) cingulata (n : number of specimens; m.l.: mean length)

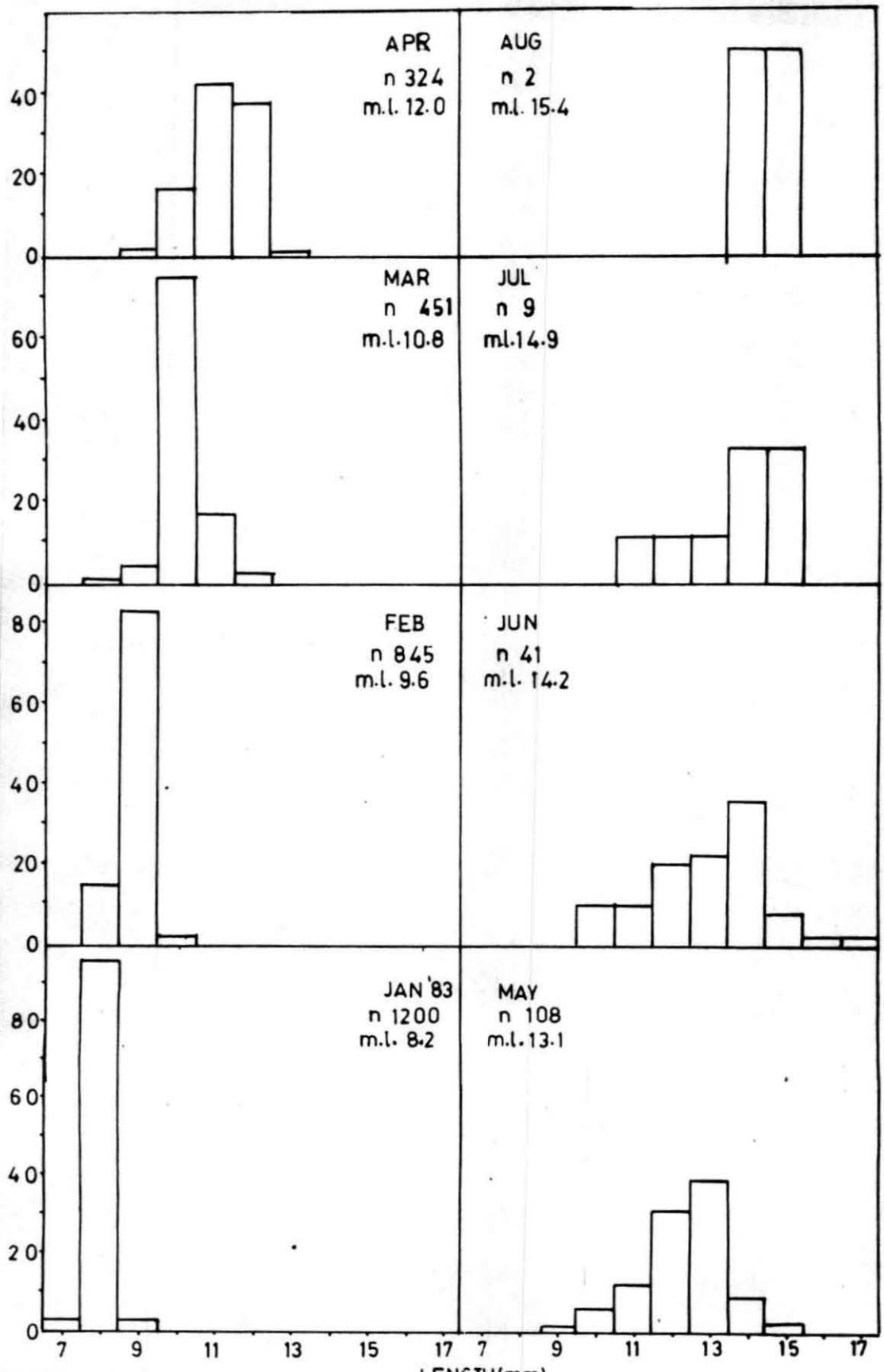

APR
n 324
m.l. 12.0
AUG
n 2
m.l. 15.4
MAR
n 451
m.l. 10.8
JUL
n 9
m.l. 14.9
FEB
n 845
m.l. 9.6
JUN
n 41
m.l. 14.2
JAN '83
n 1200
m.l. 8.2
MAY
n 108
m.l. 13.1
0
20
40
60
80
7
9
11
13
15
17
LENGTH(mm)

FIG. 63

Fig. 64. Walford Graph to find out L ∞ of C. (C.) cingulata.

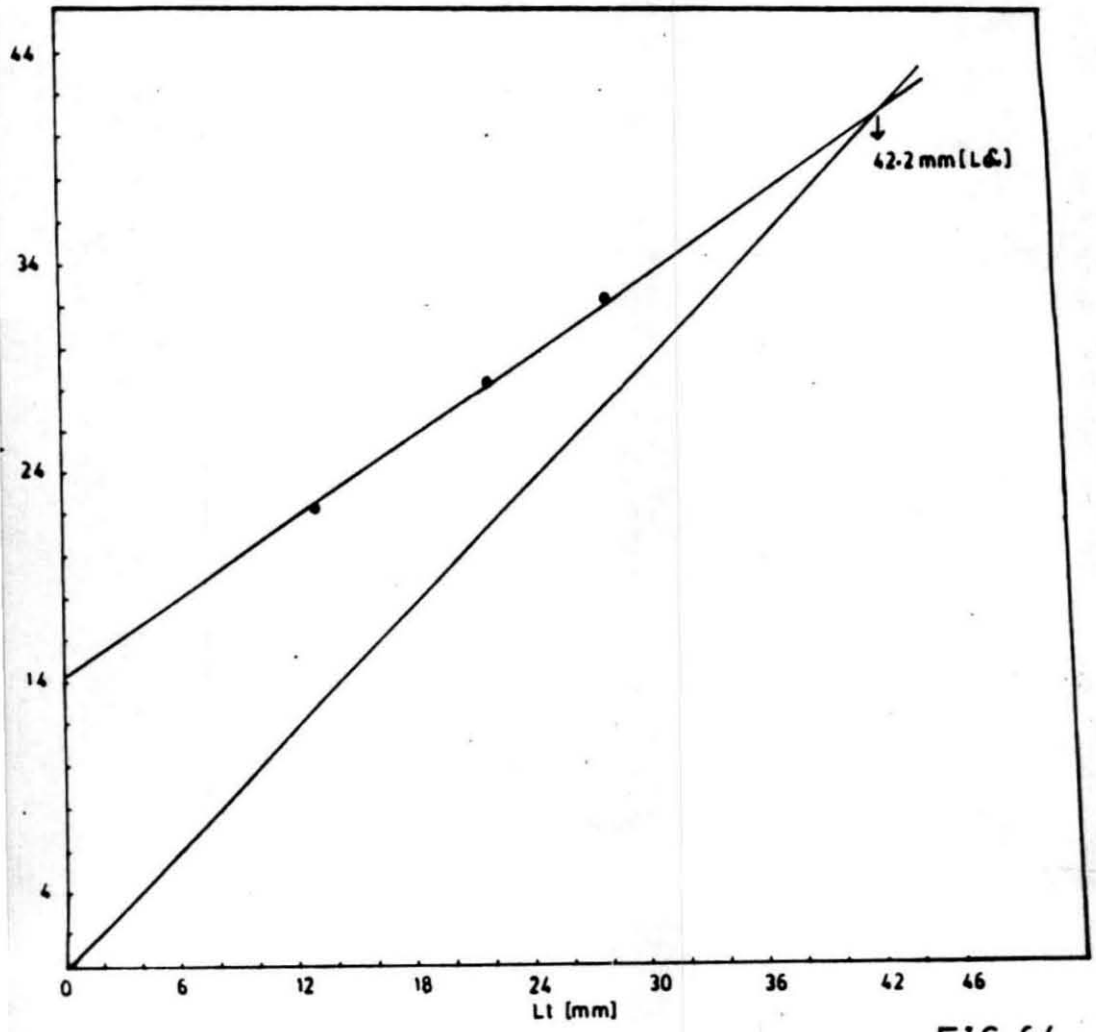


FIG 64

Fig. 65. Von Bertalanffy's growth curve for C. (C.) cingulata.

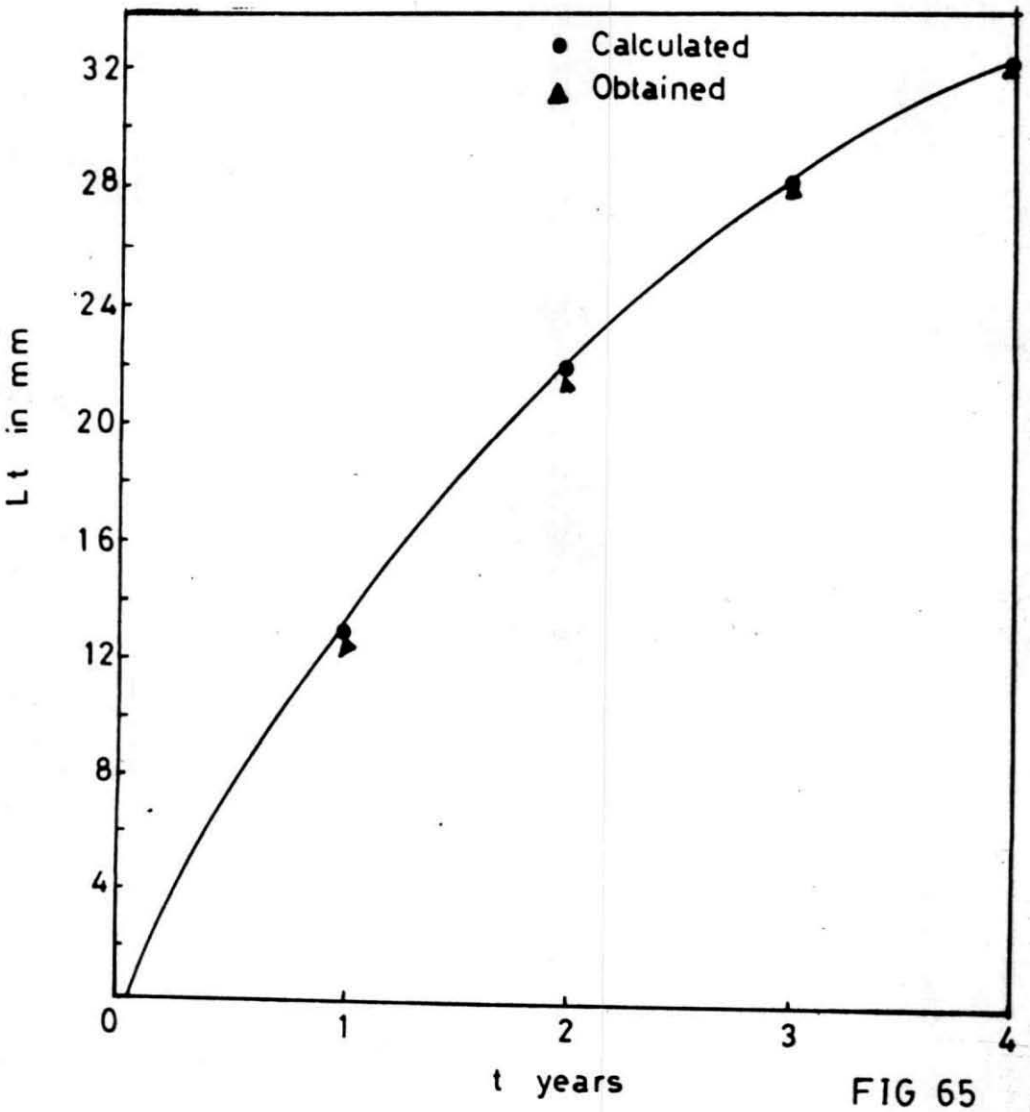


FIG 65

Fig. 66. Dimensional relationship between different parts of shell and its length.

CH : Columellar height

DO : Diameter of operculum

LBW : Length of body whorl

LH : Length of hump on body whorl

LOA : Length of oral aperture

W : Maximum width

WOA : Width of oral aperture

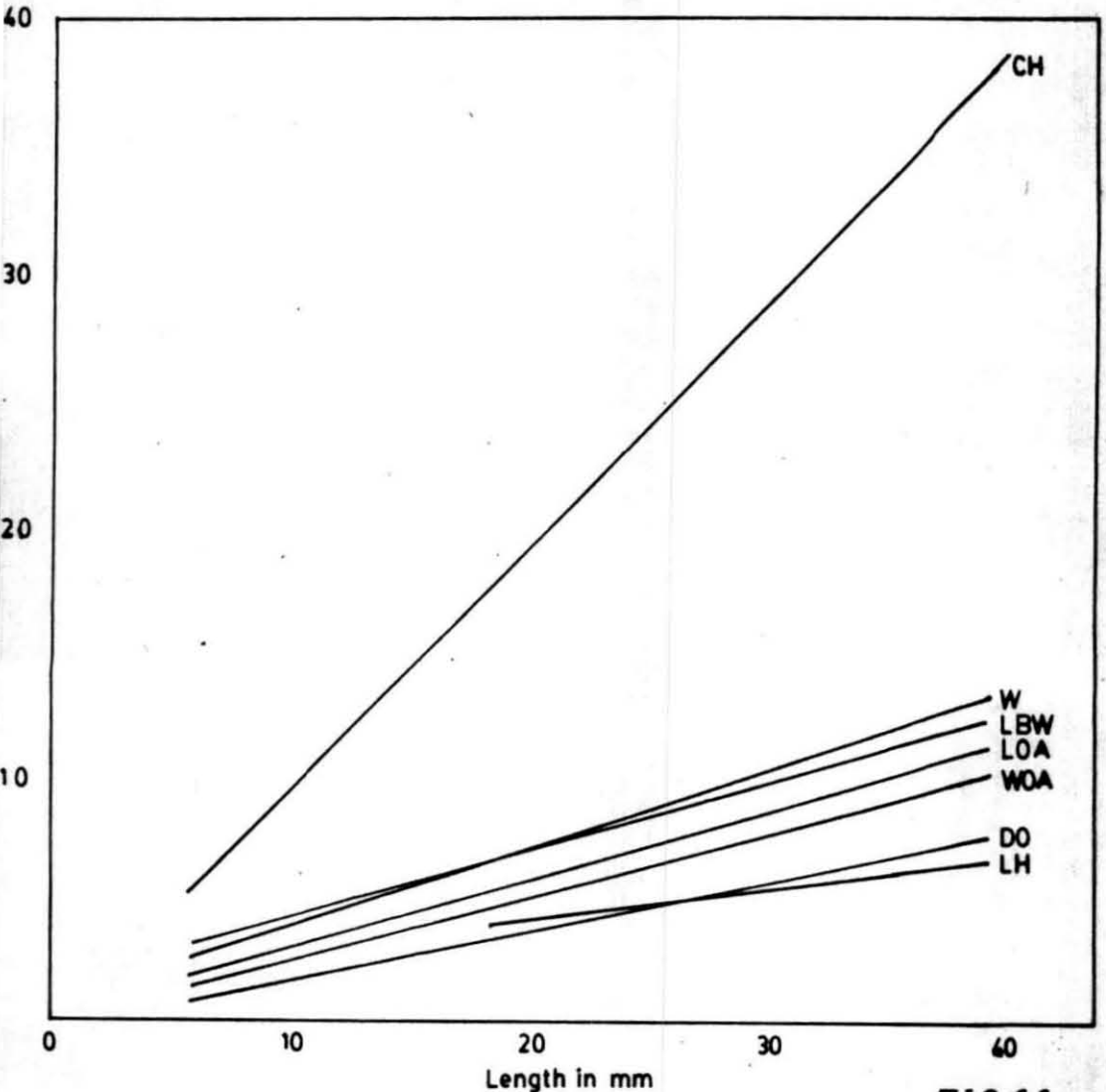


FIG 66

Fig. 67. A) Relationship between log total weight and log l.

B) Relationship between log flesh weight and log l.

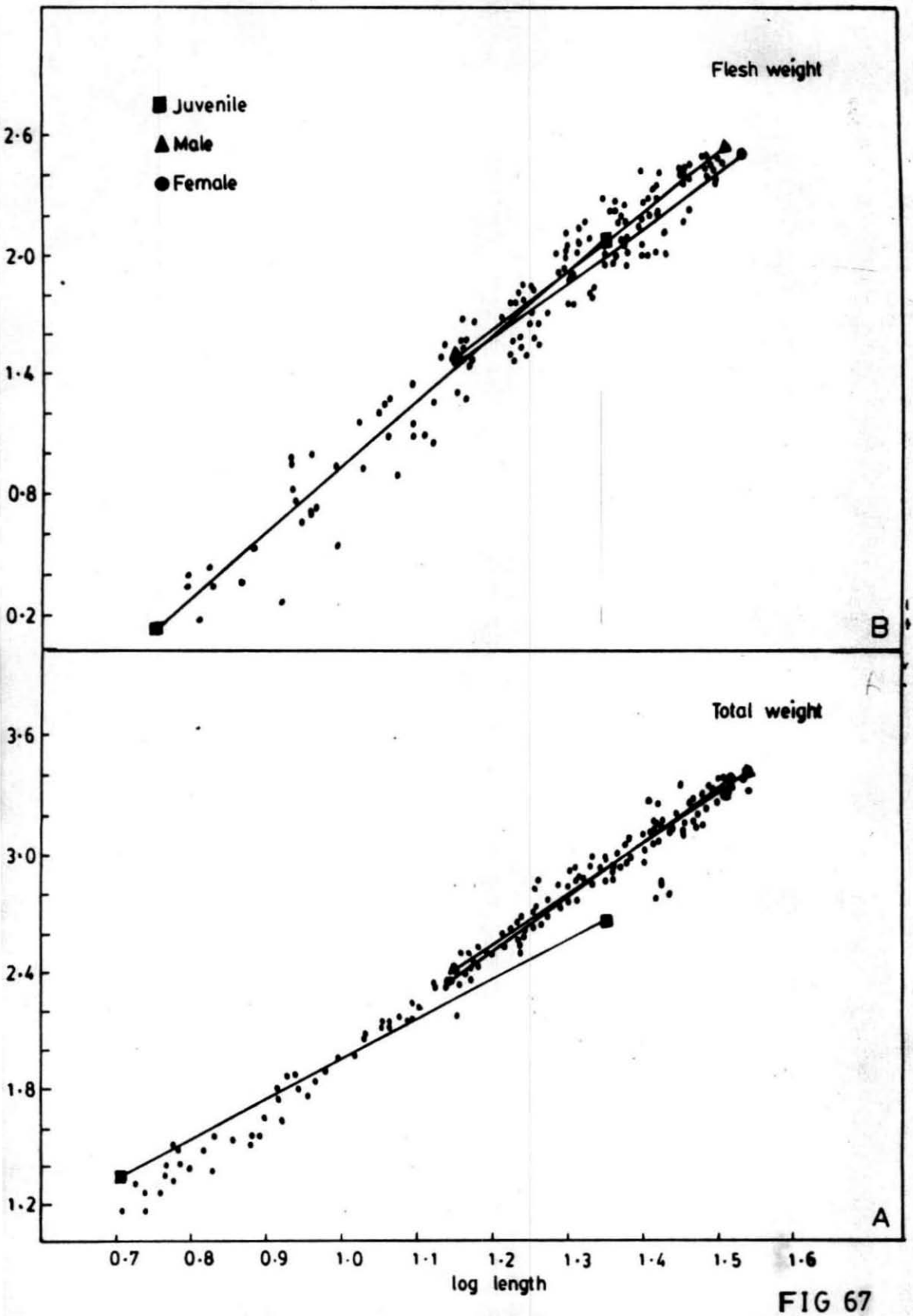

Flesh weight
Juvenile
Male
Female
2·6
2·0
1·4
0·8
0·2
B
Total weight
3·6
3·0
2·4
1·8
1·2
A
0·7
0·8
0·9
1·0
1·1
1·2
1·3
1·4
1·5
1·6
log length

FIG 67

Fig. 68. Length composition of the population of C. (C.) cingulata during the years 1982-'83 and 1983-'84.

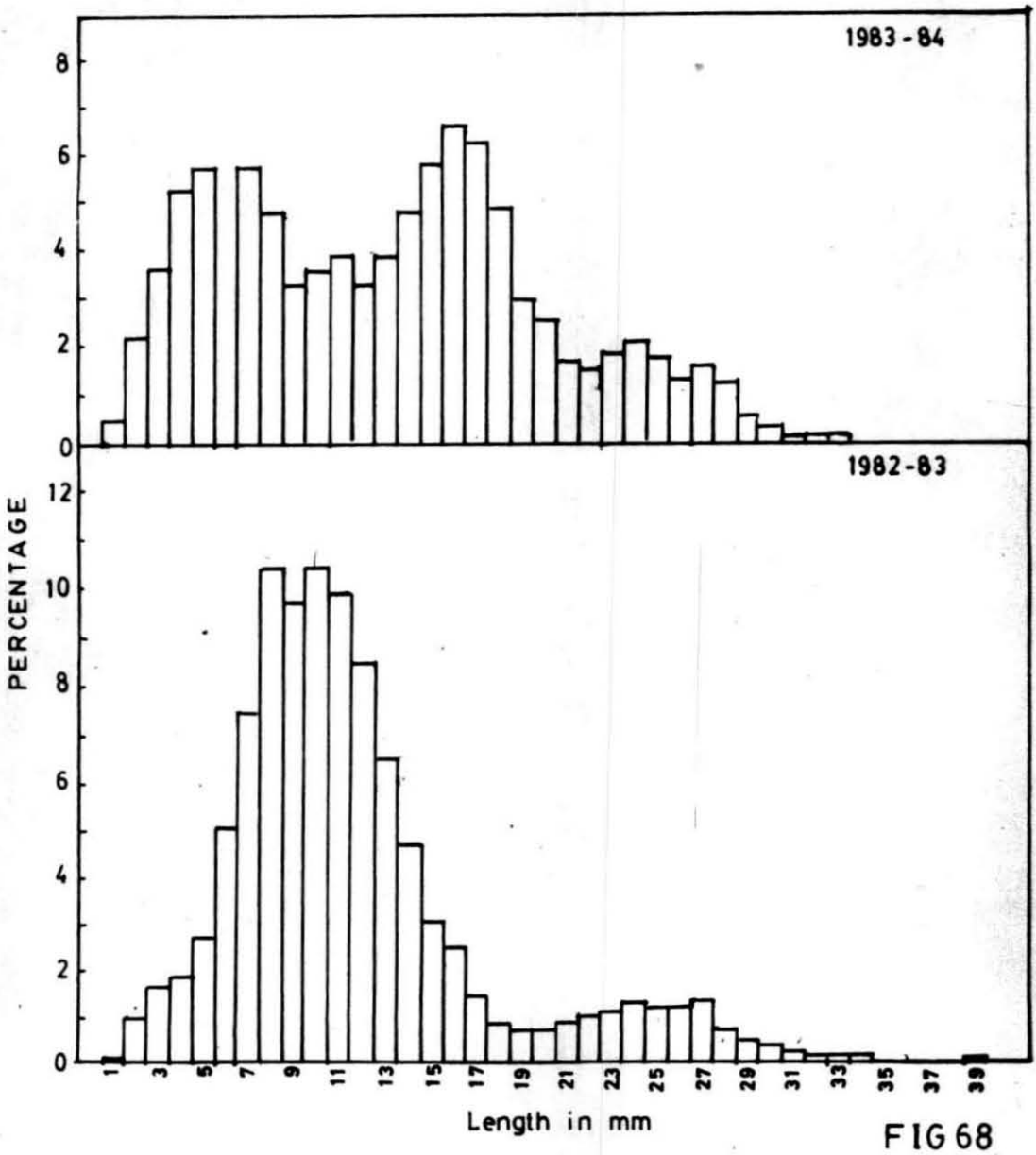


FIG 68

Fig. 69. Percentage composition of different year classes in the population of C. (C.) cingulata.

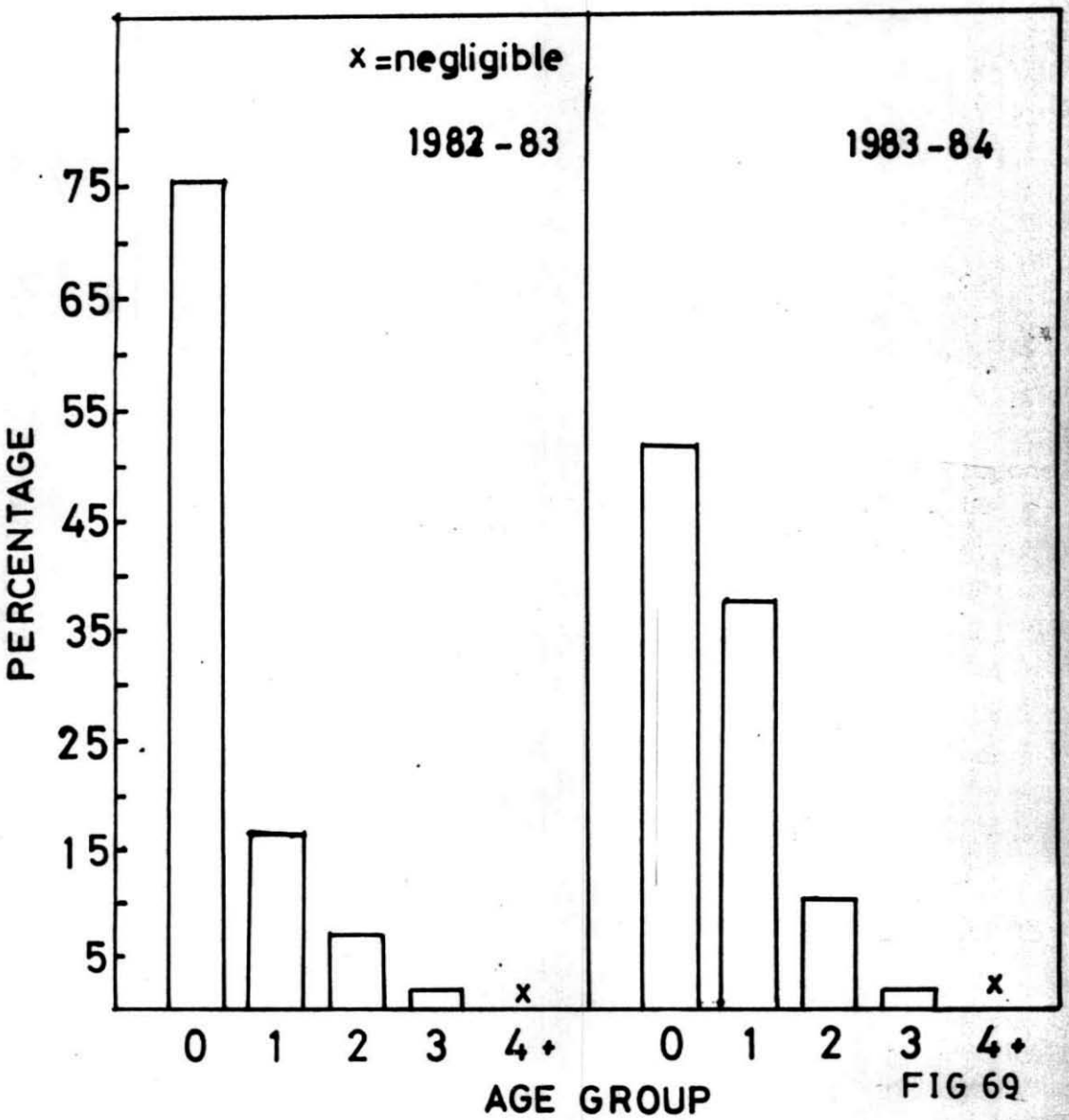

x =negligible
1982 - 83
1983 - 84
PERCENTAGE
75
65
55
45
35
25
15
5
x
x
0 1 2 3 4+
0 1 2 3 4+
AGE GROUP

FIG 69

5. DIGESTIVE ORGANS AND DIGESTION

5.1 INTRODUCTION

Style-bearing mesogastropods are unique and resemble bivalves in having the crystalline style, a proteinaceous structure. Style-bearing snails are, as a rule, herbivores (Yonge, 1930), feeding continuously on minute particles collected either by cilia or by radula. Graham (1939) first reviewed all available information on style-bearing prosobranchs with ciliary feeding. Recently, Kohn (1983) has extensively dealt with feeding biology in gastropods.

Potamidid snails are style-bearing mesogastropods and herbivores, subsisting on detrital matter and fine algal matter. The digestive systems of potamidid snails are known from the works of Seshaiya (1932), of Sadasivan (1947) on Cerithidea (Cerithideopsilla) cingulata, of Bright (1958) on C. californica, of Swaminathan (1961) on Telescopium telescopium and of Driscoll (1971) on C. californica and Batillaria zonalis. Food and feeding habits of B. atramentosa and C. californica were studied by Whitlach and Obrebski (1980) and the food of C. costata by Garret (1970). The qualitative and quantitative studies on the digestive enzymes of T. telescopium have been carried out by Swaminathan (1961). Alexander and Rae (1974), Alexander et al. (1979), Cutler

and Yellowlees (1979) and Yellowlees (1980) have studied the structure, function and enzymes of the crystalline style of T. telescopium.

A comprehensive study on C. (C.) cingulata, covering the functional morphology of digestive system, histology and histochemistry, digestive enzymes and their quantitative assessment, gut microflora and their role in digestion was undertaken and the results are discussed here.

5.2. MATERIAL AND METHODS

Specimens collected from the Vellar estuary were utilised in the present study. The alimentary tract was drawn from dissections of fresh specimens with the help of a Olympus trinocular stereo low-power microscope.

For histological and histochemical studies, fresh specimens of C. (C.) cingulata were dissected and the required organs were transferred to seperate, labelled tubes containing freshly prepared Zenker's fluid and Helly's fluid. Each organ was embedded separately after washing overnight in running water, dehydrating through grades of isopropyl

alcohol and clearing in methyl benzoate.

Double embedding in celloidin and paraffin, following Peterfi's method, as given in Pantin (1962) was used for best results. Cleared tissues were left overnight in celloidin (2% solution dissolved in methyl benzoate) and excess celloidin was removed before transferring the tissues to toluene. Celloidin solidified in toluene and the celloidin-infiltered tissues were embedded in paraffin wax at 56°C.

5 µ sections were cut uniformly, deparaffinised in xylene, and rehydrated, using grades of isopropyl alcohol. The following stains, as outlined in Drury et al. (1967) and Pearse (1977), were employed for the present study.

For histological studies:

(a) Monochrome : Heidenhain's iron haemotoxylin (Iron alum - haemotoxylin)

(b) Dichrome : Weigert's iron-haemotoxylin/Biebrich scarlet

(c) Trichrome : Masson's trichrome stain (Weigert's haemotoxylin - xylidine ponceau, chlorantine fast red and aniline blue)

For histochemical studies:

(a) For distinguishing neutral and acid mucopolysaccharides: PAS reaction/alcian Blue

(b) For sulphated mucopolysaccharides : aldehyde fuchsine.

(c) For proteins; acrolein Schiff reaction.

The stained sections were upgraded in grades of isopropyl alcohol, alcohol, acetone (50:50); acetone; acetone-xylene (50:50); and xylene (twice) and mounted with a coverslip using DPX mountant. Examination of the sections was carried out under an Olympus trinocular oil-immersion microscope and photomicrographs were taken with a Olympus photomicrographic apparatus.

For studying the movement of particulate matter in the gut, carmine was added to seawater, stirred and allowed to settle. The snail was transferred to the above water and allowed to ingest the suspension and the migration of the particles was then traced with ease.

The stomach contents were analysed in fresh condition after splitting the stomach and emptying the contents into a petri-dish, using a compound microscope.

For a qualitative analysis of the enzymes, the gut was divided into 4 sections, viz., the foregut, comprising a buccal complex and oesophagus, including the salivary gland; the midgut, comprising the stomach, and the style sac; the digestive gland; and the hindgut comprising the intestine and the rectum. Extracts were prepared by

homogenising weighed quantity of tissues with measured quantity of distilled water. The ground mixture was centrifuged at 3000 r.p.m. for 15 minutes and the supernatant was taken for further investigations. The pH of the gut was determined with BDH indicator paper, following Ward (1966).

The substrates used for determining the presence of sucroclastic enzymes were starch, sucrose, dextrose, maltose, lactose, glycogen, filter paper, agar agar and wood powder. 1% extract was incubated with 1% substrate for 3 hours in the case of sugars and for 24 hours in the case of cellulose products at 30°C. Qualitative tests were carried out using Benedict's and Bareford's reagents on the end products of digestion. A quantitative estimation of amylase activity was carried out using Somogyi-Nelson's Photometric method (Nelson, 1944). 1% enzyme extract was used to react on 1% solution of starch at a pH of 5.8 and at a temperature of 30°C for two hours. The end product was measured at 540 mμ in a spectronic-20 colorimeter, using distilled water as reference. Results were calibrated with the help of a standard curve obtained with D-Glucose.

Proteolytic enzymes were qualitatively demonstrated by the method of Harrow et al. (1960), allowing the extract

to act on the gelatinous surface of the exposed negative photofilm. In another experiment, 1% gelatin solution was allowed to react with 1% extract for 12 hours and liquefaction of the gelatin indicated protease activity (Agrawal, 1963). For quantitative estimations, 10% extract and 1% gelatin substrate were incubated for 12 hours at room temperature and the end products were estimated by Soransen's-Formal titration method as outlined by Hawk et al. (1954).

Lipolytic enzymes were examined qualitatively with 10% extract and 2% boiled milk with bromothymol blue as indicator, following Ward (1966a). After 12 hours of incubation at 37°C, the blue colour of the mixture turned yellow, indicating the presence of lipase. The quantitative estimation was carried out by the method of Tietz et al. (1959) as given in Sigma Technical Bulletin-800 (1963). One ml of 1% extract was allowed to react with 3 ml of olive oil in the presence of Tris Buffer (pH 8.0) (the indicator was Thymolphthalein) for 12 hours at 37°C. The resultant end product was titrated against 0.2 N sodium hydroxide.

In all the above estimations, boiled extracts were utilised as control and all the experiments were repeated five times. The reacting mixtures were covered with a thin layer of toluene to prevent contamination by

air-borne bacteria.

For analysing the microbial population of the digestive tract of C. (C.) cingulata, the following procedures were followed:

Specimens of C. (C.) cingulata, sediment and water samples were transferred to sterile bottles and stored in an iced chest at 4°C before transportation to the laboratory. Prior to analysis, the samples were brought to room temperature.

The specimens were washed with sterile peptone water and carefully dissected employing sterilised equipment. so as to minimise chances of contamination. The dissected portions of the foregut, midgut, the digestive gland and hindgut were washed in the sterile sea water several times, weighed and then transferred into sterile containers.

The weighed tissues were transferred to 9 ml phosphate buffered solution, homogenised and diluted serially in the ratio of 1:10. Samples of 0.1 ml serially diluted aliquots were transferred onto agar petriplates by spread plate technique in triplicates. The inoculated plates were incubated at room temperature for 1 to 4 days. Suspected colonies for Total Viable bacterial Count, (proteolytic, caseinolytic, amylolytic, lipolytic and cellulolytic bacteria)

were enumerated following the methodology of Harrigan and McCance (1972) and APHA (1976).

The media used for bacteriological analysis were those of Yoshimizu et al. (1976) for T.V.C.; Frazier's gelatin agar media with gelatin and skimmed milk for proteolytic and caseinolytic bacteria respectively (Harrigan and McCance, 1972); ZoBell's 2216 E for amylolytic bacteria; Tween agar medium for lipolytic bacteria (Harrigan and McCance, 1972) and Riviere agar for cellulolytic bacteria (Rodina, 1972).

All the results were computed for CFU/gm.

5.3 RESULTS

5.3.1 Morphology

The digestive system of C. (C.) cingulata is illustrated in Fig.70.

(a) Foregut

The mouth is a crescentic slit leading into the buccal cavity. A pair of horny jaws are located dorsally. Behind the jaws, the dorsal lining is folded longitudinally

and a pair of dorsal folds so formed are ciliated. The dorsal folds extend beyond the limit of the buccal cavity forming the beginning of the dorsal food groove. The entire buccal mass is surrounded by a thick layer of interacting smooth muscles, which allow movement in all directions including partial extrusion of radula through the mouth opening.

The radula (Fig.71.A), located in the oral cavity just above a pair of odontophores (Fig.71.B), is typically taenioglossate with one median (rachidian), one pair of lateral and two pairs of marginals (2-1-1-1-2). The radular sac opens ventrally into the posterior end of the buccal cavity. The radula extends anteriorly from the radular sac and is held against the floor of the buccal cavity by the radular membrane.

The radular ribbon measures 1.6 to 1.8 mm in specimens of 28 to 30 mm shell length, the ratio being about 0.06. The median tooth of the radula is triangular and bears a prominent middle cusp and three smaller lateral cusps on each side. The lateral tooth is larger than the median and bears six denticulations, the outer being the largest. Two marginals, inner and outer are similar in size and shape and bear six denticulations of uniform

size. The number of rows of teeth varied from 65 to 71 in snails of same shell length.

Dorsal to the radula and lateral to the dorsal ciliated grooves, a pair of salivary glands (more specifically the buccal glands) open into the buccal cavity. The salivary gland is wormlike and tubular.

Oesophagus is tubular, commencing behind the radular sac and extending to the stomach. The dorsal food groove is formed by two lateral folds, which are extensions of the lateral folds of the buccal cavity. Posterior to the nerve ring, the lateral folds twist to the left and the grooves become ventrally oriented due to torsion. The lateral folds disappear just behind the nerve ring and in the rest of the region many longitudinal folds are present. These folds increase in number towards the end of the oesophagus near the stomach.

(b) Midgut

The midgut region consists of two portions, viz., the stomach proper and the style sac without any external demarcation to seperate them.

Within the stomach of C. (C.) cingulata, the oesophagus opens midventrally, and the intestine opens topographically anteriorly (Fig.72). The digestive gland

opens by a pair of ducts adjacent to the oesophageal opening posteriorly and to the right of the latter. There is a large, midventral ridge which originates to the right of the opening of the duct of the digestive gland and extends posteriorly, ending near the base of the stomach. There are two smaller ridges, the anterior portion of one of which runs between the openings of oesophagus and intestine. This ridge prevents the food entering from the oesophagus not to be carried by ciliary currents directly into the intestine. The second small ridge extends from a point between the oesophageal opening and the opening of the duct of digestive glands, posteriorly around the base of the large ridge and anteriorly towards the gastric shield, ending about the middle of the large ridge. The gastric shield, which is only a cuticular thickening, is triangular in outline; its anterior end is slightly curved and exhibits a shallow trough into which the crystalline style is rotated. The dorsal wall of the stomach is thrown into many ciliated folds, which act as sorting areas for food particles.

The style sac is double the size of stomach and measures about 13 mm in a specimen of 25 mm shell length. The opening of the style sac lies close to the opening of the intestine, the latter lying to the left of the former.

The ventral typhlosole is seen in the form of a muscular bulge, behind the opening of the style sac and that of intestine. There is a prominent longitudinal ventral groove in the style sac.

The crystalline style normally extends along the whole of the style sac and measures about 13 mm in a specimen of 25 mm shell length, the ratio being 0.52. The style is transparent, firm but flexible, elongated, cylindrical, rod-like and does not dissolve in sea water or in fixatives like Zenker, Helly or in alcohol. The style has a blunt posterior end and a tapering anterior end. The blunt end rotates against the surface of the gastric shield.

(c) Digestive gland

The digestive gland is a coiled diverticulum, dark brown in colour, occupying the last few whorls. In mature snails, the digestive gland is interspersed with the gonad. The digestive gland is composed of numerous smaller minute tubules, closely coiled together and covered by a layer of connective tissue. As already indicated, the digestive gland communicates with the stomach by two openings, located in the midventral region.

(d) Hindgut

The intestine of C. (C.) cingulata originates from the topographically anterior side of the stomach between the style sac and stomach proper, opposite the oesophageal opening. It passes along the side of the style-sac anteriorly, before making 'S' shaped coil over the stomach. It confluences with a broad tubular rectum at the posterior end of the mantle cavity. There are a number of projections of the wall into the lumen of intestine as well as in that of the rectum. The rectum is attached to the mantle roof and opens externally through the anus, located a little behind the mantle edge.

5.3.2 Histology and histochemistry

(a) Foregut

The lips surround the mouth and lead to the oral cavity. They are lined by tall columnar epithelial cells devoid of cilia. At the anterior end of the mouth, these cells are lined by cuticle and form the horny jaws (Fig.73). These epithelial cells are contiguous with the epithelium of the snout, but the latter are taller and narrower than the former.

The dorsal food channel consists of mucous and supporting cells. The mucous cells are of two kinds, namely acid- and neutral-mucopolysaccharide secreting cells, alternating with each other (Fig.74). The radular sac has a glandular epithelial layer with prominent nuclei. The paired buccal cartilages, which resemble the vertebrate cartilage histologically, are symmetrically placed and appear J shaped. The supporting cells, which do not show any cilia, are tall, narrow, columnar, and have elongated nuclei. Mucous cells are barrel-shaped and some of them are pyriform with a basal nucleus and a prominent vacuole containing mucus. The ventral food channel also showed a similar organisation, but more mucous cells are seen here. In the posterior part of the buccal region the dorsal and ventral food channel are almost equal in size, being separated by two lateral ridges resulting in S-shaped food channel.

The tubules of the salivery glands are lined by a single layer of cells, with connective tissue and muscle fibres surrounding them (Fig.75). There are about six to eight barrel-shaped mucocytes alternating with wedge-shaped supporting cells. The mucus secreted by these cells are neutral mucopolysaccharides.

The oesophagus (Fig.76) has a mucous lining with

short wedge-shaped columnar ciliated cells with prominent oval nuclei. Barrel-shaped mucocytes (Fig.77) are also seen in the epithelial lining. There are eleven folds anteriorly, of which 8 are major and 3 minor ones. Posteriorly, these folds become uniform and number about 14 (Fig.78). Excepting for these changes in the number of folds, histologically there is not much of difference in the organisation of the oesophagus.

(b) Midgut

The lumen of the stomach is divided into numerous chambers by ridges and grooves (Fig.79,80). The epithelium, as a whole, is composed of a single row of tall and narrow cells. The mucous cells are absent in the posterior region of the stomach, which contains ciliated cells, secretary cells and absorptive cells.

The ciliated cells are long and narrow, but their lengths depend on the height of the ridges in the sorting area (Fig.81). Their cilia show metachronal rhythm and their nuclei are spiral, central, subcentral or basal, due to crowding by ciliated cells. Very fine, granular mitochondria are abundant in the apical region of these cells (Fig.82).

The secretory cells are uniformly tall and narrow

with subcentrally located nuclei, which have prominent nucleoli (Fig.83). Small to large spherical secretory granules are located in the apical part of these cells (Figs.84-86). Each such zymogen granule appears to be distinctly enveloped by a membrane which appears dark blue in Heidenhein's haemotoxylin. Further, these cells are covered by a cuticular layer. The secretory cells are apocrine, releasing the enzymes into the lumen of the stomach.

The absorptive cells are grouped as ridges. In PAS preparations, a distinct darkly staining striated (brush) border can be seen (Fig.87). The cells are long and narrow with basally located nuclei. The fine particles of food are seen to enter through the striated border and to traverse parallel to the axis of cells towards their bases. The particles of food are uniformly small-sized and are probably phagocytosed. Thus, these cells seem to be concerned with food absorption.

In the posterior region of the stomach phagocytosis by amoebocytes is discernible (Fig.88), but not much pronounced, due to the enormous area of absorption available in the stomach region. The absorptive cells appear in a sizeable number in the gastric epithelium (Fig.89).

The anterior part of the stomach has numerous

ridges and grooves, which vary in different regions. The lining is composed of tall, narrow, ciliated cells whose lengths depend on the extent to which the ridges project into the lumen. The nuclei are spherical, subspherical, elliptical or elongated, depending on the length of cells. No secretory cells are discernible in the epithelium. Very fine particles of food are absorbed by epithelial cells continuously. Amoebocytes can be seen entering through the wall, enclosing particles of food in the lumen, and freely to move back into the connective tissue and in the visceral haemocoel.

The style sac consists of mucosal lining of epithelium sorrounded by loose connective tissue (Fig.90). The epithelial cells are of two types. In the anterior tapering end of the style sac, the epithelium consists of short, broad columnar cells with cilia extending into the lumen of the sac. The cilia are as long as the cells and are closely set (Fig.91). The nuclei are spherical and basal in position. The cells of the ventral and right wall of the style sac are exceptionally tall and narrow (Fig.92) and glandular in nature. These cells are nearly thrice in length compared to the ciliated cells. Their elongated nuclei are central or subcentral in location. The cytoplasm

of the cells, which secretes the style, is basiphilic and very short cilia can be discerned in some of the cells. Nearer to the stomach region, the numbers of such secretory cells are less. The ciliated cells cover more area of the epithelial lining of the style sac.

The ventral groove is an evagination of the style sac and its walls are composed of ciliated epithelial cells with spherical prominent nuclei and another layer of cells with elliptical nuclei, with connective tissue on the outside (Fig.93). The long ventral groove assumes the form of a duct in the posterior region and ultimately communicates with the stomach.

(c) Digestive gland

Tubules of the digestive gland consist of two kinds of cells which are invested by connective tissue (Figs.94,95). The interspaces between tubules form the visceral haemocoel, where blood corpuscles and amoebocytes are located.

Among the two types of cells, the first one includes large triangular secretory cells in the corners with their bases facing the haemocoel. The second type, which occurs in large numbers, appear long, cylindrical and are digestive in function.

The secretory cell is characterised by large basal nucleus with very prominent nucleoli. These cells show yellowish or yellowish-brown excretory granules in the cytoplasm. In most of these cells are also seen spherical dark spherules which are the excretory spherules. In addition, large sized spherical secretory globules are also met with in the cytoplasm of these cells. The secretions are positive to PAS and to acrolein Schiff reactions and to Heidenhain's iron haemotoxylin, and possibly digestive enzymes of glycoprotein nature. The secretory droplets, apocrine in nature, are released into the lumen of the digestive tubules.

The secretory cells thus seem to perform a dual role of secretion and excretion. The excretory spherules are released into the lumen (Fig.96) from where they pass into the stomach and to the hindgut, to be compacted with faeces.

The digestive cells of the tubules are long and cylindrical. Their nuclei are relatively small. The cytoplasm shows large number of vacuoles and other inclusions. Yellowish green pigments, in the form of irregular masses, seen in the cytoplasm, do not stain with any cytoplasmic stains. The digestive cells are not of uniform height and,

as a result, the lumen appears irregular in outline. The apical regions of these cells are dome-shaped.

The digestive gland also shows phagocytic activity; amoebocytes are found in the haemocoel, in the tubules and in their walls (Fig.97).

(d) Hindgut

The lumen of the intestine (Fig.98) is lined by two kinds of cells, the supporting ciliated cells (Fig.99) and the secretory cells (Fig.100). The secretory cell is pyriform with a basal spherical or subspherical nucleus and prominent nucleoli; the spherical secretory granules are large or small and fill the cytoplasm in large numbers in the apical region before being discharged. These cells show long filamentous mitochondria, particularly in the apical region. The secretory droplets can be well seen being released into the lumen (Fig.101). The secretory granules are positive to acrolein Schiff (Fig.102) and PAS reactions (Fig.103) and are intensely stained by Heidenhain's iron haemotoxylin indicating their glycoprotein nature. Secretions are apocrine as observed in the stomach.

The supporting cells are long with elongated subcentral nuclei. The long cilia show metachronal rhythm. The outer wall of the intestine consists of connective

tissue and muscle fibres.

There is pronounced phagocytic activity in the intestine by amoebocytes. These amoebocytes can be seen in various stages of infiltration from the haemocoel through the wall of the intestine. The amoebocytes are also seen to engulf the food particles after which they again move through intestinal wall. They then deposit the food particles in the connective tissue surrounding the digestive tract. It is to be noted that phagocytosis augments the assimilation efficiency of the digestive tract although it is a primitive method of digestion. Perhaps due to abundant availability of nutritive material in food, active phagocytosis has been resorted to, besides intracellular digestion in the digestive tract.

Rectal wall consists of an outer membranous layer, a middle connective tissue layer and inner mucosal layer (Fig.104). There are seven to eight folds in the mucosal lining. The mucous layer consists of broad, large elliptical or oval epithelial cells. The nuclei are large and elliptical or oval. These cells bear uniformly short cilia. There are a number of barrel-shaped cells which produce both acid and neutral mucopolysaccharides (Fig.105).

(e) Hypobranchial gland

This gland even though is not a part of the digestive tract, helps in consclidation of faeces and of food particles (Graham, 1938) and prevents fouling of the ctenidium. Therefore, it is considered here alongwith the digestive system, but not as a part of it.

The hypobranchial gland is a closely attached ridge between the ctenidium on its left side and the hindgut on the right side. In the anterior part of the mantle cavity, it is broad, occupying almost half of the mantle roof on the right side of the mantle. It is divided into two halves by the rectum, one half lying between the rectum and ctenidium and other between the rectum and the genital ridge. Further backwards, the intestine runs between the mantle wall and the hypobranchial gland.

The hypobranchial gland has mucous secreting cells and tall ciliated cells lying in between (Fig.106). In addition there are pyriform cells filled with fine granules which appear to be proteinaceous.

The mucous cells are of two kinds, secreting neutral or acid mucus. The ciliated cells have fairly long cilia. The connective tissue binds the hypobranchial gland to the mantle wall and to the wall of the hindgut.

The secretory activities found in the alimentary tract of C. (C.) cingulata are summarised in Table 19.

5.3.3 Food and feeding habits

C. (C.) cingulata subsists mainly on detritus present in the substratum where the snail lives. From the distribution of the snail in the Vellar estuary it can be understood that it prefers soft, fine sandy substratum and can be considered as a selective bottom-feeder. Periodic inspections of stomach contents indicated the presence of fine detrital matter, sand grains, unicellular diatoms such as Navicula, Nitzschia, Coscinodiscus, Fragillaria, Pleurosigma and minute scraps of algal filament. In the laboratory, C. (C.) cingulata was observed to rasp on algae provided in addition to rasping-off the fine substratum.

During feeding, the snail extends its protrusible snout and with the help of the radula, rasps the substratum and ingests fine particles. The snail makes short feeding excursions during low tide near the water edge. Such movements leave characteristic curved or zig-zag trails in the soft substratum.

The snail survives starvation upto 30 days without

mortality. The material in the gut seems to last for 5 or 6 days, after which there was no production of faecal strings. During active feeding, faecal strings, mixed with a lot of mucus, are excreted and these contain undigested plant material and sand grains.

5.3.4 pH in the gut

Hydrogen-ion-concentration in different parts of the gut are given in Table 20. The buccal cavity is neutral and the rectum is slightly alkaline. The oesophagus, digestive gland, stomach, style sac and intestine are acidic and the style is the most acidic.

5.3.5 Digestive enzymes

(a) Qualitative analysis

The results of the tests carried out to record the nature and activity of enzymes present in the digestive tract of C. (C.) cingulata are given in Table 21. Of the ten substrates of carbohydrases, complex polysaccharides such as filter paper, cotton wool, saw dust and agar agar, were not acted upon by extracts from any of the four regions

indicating the absence of cellulase in any part of the alimentary tract. Glycogen, dextrose and sucrose are digested in the digestive gland and the midgut, while starch, lactose and maltose appear to be hydrolysed in all parts of the tract excluding foregut.

Proteolytic activity was observed only in the extracts of digestive gland and there too, it was weak. Lipolysing capacity of the digestive system of C. (C.) cingulata, was also confined to the digestive gland region only and the lipases were found to be weak.

The foregut did not show any digestive enzyme, which is in accordance with the findings of histological and histochemical studies described earlier. The secretions of the midgut included the di- and polysaccharases released by the crystalline style as well as those from the secretory cells of the stomach wall. The secretory cells in the mucosa of the intestinal region account for the activity of the disaccharases, maltase and lactase, recorded mostly in the hindgut.

The digestive gland serves as the main source for proteases and lipases and also for carbohydrates. From the tests it is again confirmed that the activity of the former two are confined to the digestive gland region only.

(b) Quantitative analysis

The activity of amylases, proteases and lipases in four different regions of the alimentary tract are given in Table 2[illegible].

As stated earlier, extracts from the foregut region did not show any enzyme activity. Amylase activity is high in the midgut followed by the digestive gland and the hindgut. Proteolytic and lipolytic activities could be recorded only in the digestive gland.

5.3.6 Gut microflora

The distribution of different groups of microflora in the gut of C. (C.) cingulata and in the water and sediment samples are given in Fig. ~~107~~.

The T.V.C. varied from 1×10^{-4} CFU/gm in the digestive gland to 1.58×10^{-5} in the hindgut of the alimentary tract, which was higher than the concentration found in water, but lower than the sediment values. Similarly, gelationolytic bacteria varied from 2.9×10^{-3} CFU/gm in digestive gland to 1.16×10^{-4} CFU/gm in the foregut; caseinolytic microbes varied from 1.31×10^{-3} in the digestive gland to 5.8×10^{-3} in the foregut; amylolytic

bacteria from 7.6×10^{-2} in the digestive gland to 3.03×10^{-4} in the hindgut; cellulolytic bacteria from 6.6×10^{-3} in the digestive gland to 1.56×10^{-4} in the foregut; and lipid-users from 1.27×10^{-3} in the digestive gland to 5.2×10^{-3} in the foregut.

Amylolytic bacteria were, more dominant in the gut as a whole, followed by gelatinolytic bacteria and cellulolytic bacteria in that order. Caseinolytic and lipolytic populations were quite low.

In general, the microbes were found to be more in the sediment than in the water or in the gut. Among the various regions, the digestive gland harboured the least number of bacteria followed by the midgut. Least number of bacteria recorded in the digestive gland could be attributed to the ingesting of bacteria by phagocytes in the lumen (Payne et al., 1972) and unsuitable pH. Both the foregut and the hindgut recorded highest number of microbes. The distribution of bacteria in different regions is also indicative of the fact that the digestion of unused substrates were acted upon by the microbes in order to supplement the nourishment of the snail.

5.4. DISCUSSION

The important features of the digestive system of C. (C.) cingulata based on its mode of feeding are: (1)a long protrusible snout, (2)reduced buccal mass with well-developed musculature, (3)narrow and short radula, with a few recurved cusps, (4)a long, straight oesophagus with many epithelial folds dividing the lumon into food channels, (5)a much reduced wormlike salivary gland secreting only mucus, (6)a well-developed sorting system in the stomach, with a large typhlosole and smaller ridges, and a well-developed gastric shield, (7)a crystalline style enclosed in a style sac, (8)well-developed digestive gland which is the main source of proteolytic and lipolytic enzymes though weak, (9)a long, coiled intestine with absorptive and digestive functions, (10)the anus, shifted towards left to eliminate faecal matter to avoid contamination of the ctenidium; and (11)pronounced phagocytic activity by amoebocytes in the stomach, digestive gland and in the intestine. The significant feature is the absence of well developed musculature except in the region of buccal mass, where the muscular movement is involved with the functioning of the buccal cartilage and radula.

The organisation of the buccal region is similar

to other potamidids described by Bright (1958) in C. californica, by Driscoll (1972) in C. californica and B. zonalis and by Swaminathan (1961) in T. telescopium. The extensible snout, with strong musculature, helps in swallowing the food particles. Swaminathan (1961) compared the ratio of buccal mass in relation to total length of the digestive system in T. telescopium, Pila virens and Melania crenulata and concluded that the extensive buccal mass is related to rhythmic feeding. In a continuous feeder, like T. telescopium, the buccal mass is comparatively smaller, and similar is the case with C. (C.) cingulata.

The taenioglossate radula of C. (C.) cingulata suits the benthic microphagous feeding habit. It has fewer teeth and a less complex musculature (Fretter and Graham, 1962) and can be considered as the most successful of all gastropod radular types (Kohn, 1983). The less development of musculature reflects a change from sweeping mode of action to scrapping or rasping mode of feeding. Therefore, less emphasis is laid on the positional adjustments of the radula, but more on the force with which the radula is applied to the substratum. According to Fretter and Graham (1962), the median teeth of taenioglossate radula help in collecting the food, while the pleuricuspid marginal and laterals have more

area for collecting particles by their splaying action (Steneck and Watling, 1982).

Fretter and Graham (1962) correlated the ratio of radular teeth with the size of the snail and the type of substratum in which the animal lives. Driscoll (1971) found the radular ratio of 0.11 for B. zonalis and 0.09 for C. californica. According to him, the former lives on much coarser substratum than the latter. Presently, the ratio obtained indicates that C. (C.) cingulata can thrive only on finer sediments.

The reasons for reduction of salivary glands in the style-bearing gastropods could be the major involvement of the crystalline style in the secretary activity, making redundant the secretory function of the salivary glands (Graham, 1939). Unlike in pulmonates, where the salivary glands function both as enzyme secretors for splitting carbohydrates as well as for production of mucus to lubricate the radular movement (Meenakshi, 1954), the salivary gland in C. californica and B. zonalis was observed to secrete mucus only (Driscoll, 1971). Swaminathan (1961) reported the presence of amylase in the salivary gland of T. telescopium. Fretter and Graham (1962) also reported the presence of digestive enzymes in the secretions of salivary gland in

a few Prosobranchs. In the case of C. (C.) cingulata, however, these glands appear to serve only the function of mucus-secretion for binding the food material, but not for secretion of digestive enzymes.

Passage of food from the oral region to the posterior region of the buccal cavity of C. (C.) cingulata takes place by the currents created by the ciliary beat in the dorsolateral food channel. Driscoll (1971) observed in C. californica that these currents efficiently channelised the food material away from the radula and towards the oesophagus, thereby preventing the buccal cavity from getting clogged. The water-mixed fine sediment poses no serious problem for ciliary transport through the buccal region.

The simplicity of the oesophagus is striking when compared to the non-style-bearing prosobranchs. Oesophagus, in style-bearing snails, serves only the function of transportation of food (Graham, 1939). The presence of lateral folds and occurrence of mucus-secreting glandular cells and ciliated cells in the oesophagus of C. (C.) cingulata, are in general agreement with the previous observations of Bright (1958), Swaminathan (1961) and Driscoll (1971) on potamidids. The elongated oesophagus appears to compensate for the loss of oesophageal pouch

found in herbivorous prosobranchs and pulmonates.(Swaminathan, 1961).

The glandular cells of the oesophagus in prosobranchs secrete enzymes, as observed by Graham (1932) and Fretter (1937), but only mucus for consolidation of food particles, in the case of B. zonalis and C. californica, as stated by Driscoll (1971). In the case of C. (C.) cingulata, oesophagus appears to be a region of transportation of food particles bound by mucus secreted by the glandular cells.

The occurrence of crystalline style is a noteworthy feature for consideration. According to Yonge (1930), the possession of crystalline style is associated with microphagous herbivorous food habit. He further generalised that the presence of crystalline style can also be taken as an indication of absence of free proteolytic enzymes in the gut.

The presence of style ensures an enzyme-supply sufficient to fully digest the available food material, which is advantageous for a slow, continuous feeding mollusc. Therefore, an increase in style length would provide an increase in the supply of digestive enzymes. Graham (1932) pointed out the alterations seen in other glandular structures

on account of the presence of style. According to him, the reduced salivary gland and the loss of oesophageal pouch are associated with the presence of crystalline style. Seshaiya (1929a,b,'30,'32,'34) while describing the structure and function of the crystalline style among mesogastropods, concluded that originally the stomach and style sac were combined, but in the course of evolution have become separated.

The crystalline style in T. telescopium, was found to contain 14 amino acids, of which 11 were observed to be free as well as bound, while 3 were bound aminoacids (Swaminathan, 1961). The site of secretion of the crystalline style has been suggested to be a narrow strip of cells along the typhlosole (Fretter and Graham, 1962) and also by the glandular cells along the ventral groove, but primarily at the distal end of the style sac (Driscoll, 1971). Alexander and Rae (1974) held that the distal end of the style sac should be solely responsible for style secretion. It is of interest to note in C. (C.) cingulata that the distal end of the style sac seems to contain more area for style secretion than the typhlosole region of the stomach, where only a very narrow strip of glandular cells are observed. It appears that in this species, the secretion of style could

be from the distal end (tapering end) as observed by the latter authors.

Yellowlees (1980) stated that enzyme activity in the style region was due to the combined effects of secretions from the style, from the glandular cells in the style sac and also from the secretions of the stomach wall. Morton and Stone (1958) observed the presence of various polysaccharide- and glycoside-hydrolysing enzymes in the walls of the stomach. The present study on C. (C.) cingulata, also shows the presence of enzyme-secreting cells in the posterior part of the stomach.

The structure and internal anatomy of the stomach are similar to those of C. californica, B. zonalis and T. telescopium (Bright, 1958; Swaminathan, 1961; Driscoll, 1971). The pattern of the opening of the digestive glands, oesophagus, intestine and style sac, is strikingly similar in all these forms. The presence of typhlosole, grooves and ridges in the stomach, is to direct the gastric contents towards the gastric shield region. These ciliated ridges and grooves create vortex currents for transportation of food particles first towards the gastric shield, then towards the digestive gland for absorption and lastly towards the intestine for elimination of waste material in the form of

faecal strings. Driscoll (1971) suggested that the muscular movement of the stomach also aids in pushing the food materials into the digestive gland and also in drawing out the undigested food material from the digestive gland.

The general organisation of the digestive gland agrees with earlier findings on prosobranchs in general (Fretter and Graham, 1962). According to them, the digestive gland varies considerably amongst prosobranchs based on types of food ingested and a rhythmic activity related to secretion. They described the presence of two types of cells, the digestive cells and the secretory cells in the digestive gland. Morton (1967) has described in detail, the functional modality of the digestive gland. Both intracellular and extracellular digestion appear to take place in this region. Transportation of food material within the digestive gland was attributed to ciliary current in the tubules and also to muscular contraction (Driscoll, 1971), but the former was considered to be the whole means of transportation by Morton (1967). The cells of the digestive gland appear to be both secretory and excretory in nature, as observed by Driscoll (1971).

Bright (1958) and Driscoll (1971) stated that the gland cells in the intestinal region are mostly involved

with mucus-secretion for binding the faeces. On the other hand, in the present observation, these cells are involved in the secretion of digestion ensymes. In addition, the intestine was also observed to be an area of active absorption.

Rectum is the region for consolidating the faecal matter and so is replete with elaborate mucus-secreting cells, confirming the findings of earlier authors.

Feeding behaviour in C. (C.) cingulata is similar to that of T. telescopium (Swaminathan, 1961), and of B. zonalis and C. californica (Driscoll, 1971). Among the gastropods, chemoreception appears to be most important for identifying the food along with vision and tactile perception of surface texture (Kohn, 1983). Feeding responses in these snails are subjected to modifications including habituation, sensitisation, satiation and associate-learning. Their food items include benthic diatoms and algal materials settled and decayed on the substratum, as observed by Whitlach and Obrebski (1980) in the case of Batillaria and Cerithidea.

The detrital matter in sediment was found to contain both living and decaying plant material full of polysaccharides. Efficiency of the digestive system will naturally depend on suitable enzymes to digest complex

polysacchrides, including the cellulose, a common constituent in the plant material. The enzymes in the digestive system vary between the species depending on the habitat, nature of food available, feeding type, food preferences and duration of food in the gut (Calow, 1975).

Hydrogen-ion-concentration in the gut varied from neutral in the buccal region to acidic in oesophagus, stomach, digestive gland and style sac, gradually becoming alkaline in the rectum. Binding effect of mucus appears to be higher in an alkaline medium than in the acidic medium. Therefore, neutral pH in the buccal region helps to bind the food material to be transported to the oesophagus, while alkaline pH in the rectum helps to bind the faeces with the mucus in the form of strings. Hyman (1967) has also stated that pH in the hindgut was higher than in the midgut. In the acidic medium of the oesophagus, the stomach, the digestive gland and the intestine, the mucus dissolves so as to release the food particles for enzymatic action. The acidic pH also is suitable for the optimum action of digestive enzymes. Similar observations were made by Swaminathan (1961), Balaparameswara Rao (1975b) and Manmadha Rao (1977), on other prosobranchs.

The presence of amylase, maltase, invertase,

lactase and glycogenase and the absence of cellulase in the gut are indicated by the present study on C. (C.) cingulata. The midgut and the digestive gland and to some extent the hindgut are the regions where enzymes have been recorded. Presence of amylase and a weak glycogenase in the salivary gland was noted by Meenakshi (1955) in Melania crenulata, by Swaminathan (1961) in T. telescopium and amylase only by Nanmadha Rao (1977) in Clypeomorus sp. Presence of many carbohydrases was reported by Gallie and Giese (1959) in Tegula funebralis. In the present observation, no enzyme activity could be discerned in the foregut.

High activity of carbohydrases was observed in the midgut probably due to the secretory activity of the crystalline style, the enzymes of which are mainly carbohydrases. Meenakshi (1955), Swaminathan (1961), Nanmadha Rao (1977) and Yellowlees (1980) observed the occurrence of amylase and glycogenase in secretions of the style. Hashimoto and Onoma (1949), Morton and Stone (1958) and Yellowlees (1980) found evidences for sucroclastic enzyme secretions in the stomachs of gastropods studied by them. The secretory activity of the stomach wall, as found in the present study, is similar to the above observations. It is also to be noted that the secretory cells occur mostly in the posterior region of the stomach of C. (C.) cingulata adding to the

enzyme pool contributed from the digestive glands.

Occurrence of amylase and carbohydrases has been reported previously from the digestive gland of prosobranchs by Swaminathan (1961), Ward (1966a), Balaparameswara Rao (1975b) and Manmadha Rao (1977). In C. (C.) cingulata also, amylase, maltase, invertase, lactase and glycogenase have been found to occur in the digestive gland. However, regarding the quantity of glucose released, the activity of the digestive gland is lower than in the midgut.

The presence of cellulases in the digestive system of prosobranchs has always been a subject for conflicting opinions. Morton and Stone (1958) have reviewed in detail the occurrence of cellulases among molluscs and concluded that in many molluscs they are present. Felbeck et al. (1983), however, indicated that animal genomes appear to lack information-coding for complete set of enzymes required for degredation of wood. Reports are available regarding endogenous cellulase in a number of gastropods and bivalve molluscs (Morton, 1978), but in others, the cellulolytic function appears to be performed by enzymes synthesised by symbionts, notably the gut bacteria (Felbeck et al., 1983). C. (C.) cingulata also lacks cellulase though it has been reported to occur in T. telescopium by Swaminathan (1961),

in Clypeomorus sp. by Manmadha Rao (1977) and in Melania sp. by [illegible] (1955). Ward (1936a) and Balaparameswara Rao (1975b) failed to record any cellulase from the gut of Fissurella barbedensis and Cellana radiata, respectively, in spite of the dependency of these snails on algal diet. Balaparameswara Rao (1975b) further stated that C. radiata lacked polysaccharases and was not able to utilize the complex polysaccharides, such as cellulose, agar agar, etc. The snail secreted sucrase, which acted upon sucrose - a reserve product of the plant and utilised the same as nourishment.

Occurrence of proteolytic enzymes is again a matter for differing opinion among style-bearing meso-gastropods. No protease could be detected in the digestive system of Melania by Meenakshi (1955) and in T. telescopium by Swaminathan (1961). Relatively weak protease was found to occur in the digestive gland of Clypeomorus sp. by Manmadha Rao (1977). A weak protease activity could only be observed in the digestive gland extract of C. (C.) cingulata. Absence of proteolytic enzymes is a general feature in style-bearing gastropods as a safeguard against dissolution of the crystalline style.

The presence of very weak lipolytic enzymes was

in T. funebralis. The importance of microflora in cellulose-hydrolysing activity has been brought out by the work of Parnas (1961) on normal and antibiotic-treated Lavantina hierosolyma. Kristensen (1972) has made a general observation that bacterial enzyme production in the gut of animals plays a pivotol role in digestion, especially of polysaccharides which are not easily digestible by the digestive enzymes produced by the animal. Mansour-Bek (1954) stated that most animals do not possess the enzymes necessary to initiate hydrolysis of carbohydrates, although flora of alimentary tract may do so. Kasinathan et al. (1973) found that a cellulolytic enzyme pool, secreted by the gut and also by the cellulolytic bacteria in the alimentary tract of Cyclophorids, helps in the digestion of cellulose in those snails.

It is of interest to note that in regions of high enzyme activity viz., the digestive gland and the midgut, the bacterial population is much less when compared to foregut and hindgut where enzyme activity is meagre or absent. Wright and Hobbie (1966) observed that the intestinal microbial flora are capable of utilising dissolved organic substances even at low concentration for nutritional purpose and this may be true in the case of C. (C.) cingulata also,

which accounts for the heavy microbial load in the hindgut. In the entire gut, complex polysaccharases are totally absent, and so the snail seems to be dependent on the gut microflora to convert them into simpler products which then can be acted upon by the native enzymes. In the same way, the amylolytic and cellulolytic bacteria present in the foregut probably convert the food to simpler sugars to be acted upon by sucroclastic enzymes secreted by the midgut.

The undigested or unabsorbed carbohydrates reach the intestine from the stomach. The disaccharases present here split than and release the monosaccharides for absorption by phagocytosis. The faecal matter rich in residual carbohydrates, may serve as a substrate for a flourishing bacterial population in the intestine and rectum, as noted.

Gelatinolytic, caseinolytic and lipolytic bacteria are more in the foregut and hindgut than in the midgut, the least being in the digestive gland.

In general, the bacterial populations flourish most in the foregut region, where enzyme activity is meagre or absent and in the hindgut region where the residual undigested food, rich in various substrates, offer the best opportunity for proliferation. Their numbers decline considerably in the midgut and the digestive gland where

substantial enzyme activity is present.

It can be said, that, the heterotrophic bacteria in the gut of C. (C.) cingulata have an active role to play in the digestion of food and their numbers in various regions of the gut are inversely related to enzyme activity in that region. Wherever enzyme activity was absent, the bacteria became complementary in function and helped in digestion, thus playing a significant role in the digestive processes of the snail.

To sum up, the food of C. (C.) cingulata which is detrital organic matter rich in saccharides, is rasped with the help of the radula and then ingested alongwith fine sand particles. Mucus from simplified tubular salivary glands and the wall of the buccal cavity help in binding these food particles. Neutral pH in this region is advantageous for the binding of food particles by mucus. The oesophagus, a simple tube lined with mucocytes and ciliated cells, does not secrete any enzymes and so digestion by native enzymes is absent in this region. Preliminary degradation of food particles takes place in this region by the action of amylolytic, cellulolytic, gelationolytic, caseinolytic and lipolytic bacteria, present there in large numbers. The resultant simpler products, reach the stomach, where the

native enzymes act upon them.

The food particles enter the sorting area where the ciliated cells actively move the particles, in a whirlpool, to the posterior part of the stomach. The stomach wall possesses secretory cells, absorptive cells and ciliated cells for digestion, absorption and transportation. Both extra- and intracellular digestion take place in the stomach. Coarse particles are moved towards the intestine from the sorting area, by ciliary action and the finer particles are pushed towards the digestive gland for intracellular digestion. Phagocytic activity is also pronounced in both the stomach and the digestive gland. Amoebocytes engulf the food particles from the lumen, transport them through the wall to the connective tissue for storage.

Extracellular enzymes for digestion are secreted by the digestive gland and stomach wall into the lumen of the stomach. In addition, the crystalline style releases enzymes by rotating against the chitinous gastric shield. All these enzymes are glycoprotein in nature and act mostly on carbohydrates. The digestive gland, on the other hand, secretes weak proteolytic and lipolytic enzymes. There is no microbial activity in the stomach or in the digestive gland. Partially digested food particles and waste products,

from the stomach and the digestive gland, are moved by ciliary action into the intestine. Acid pH in these two organs offer optimal conditions for enzymatic activity.

In the intestine, the undigested food particles undergo further degradation by the secretions of the intestinal wall. The intestinal cells and the amoebocytes actively involve themselves in the absorption of remaining digested food. The ciliated cells help in transporting the undigested particles into the rectum. The rectal wall contains mucocytes which secrete acid- and neutral-mucopolysaccharides to bind the faecal matter into strings to be expelled through the anus. Extensive bacterial activity in this area utilises the waste organic matter for luxuriant growth. The hypobranchial gland also aids in consolidation of the faeces.

The salient findings of the present study on the digestive organs and digestion are:

(1) Mouth is a vertical slit lined by cuticular layer internally.

(2) The buccal region is invested with complicated muscles to aid in the protrusion and retraction of the snout.

(3) Two pairs of buccal cartilages are present in the oral cavity.

(4) Taenioglossan type of radula, with one median, two laterals and 4 marginals (2-1-1-1-2), is present. The radula is secreted by the radular sac.

(5) Buccal cavity is divided into dorsal and ventral grooves by lateral muscles. The wall is lined by mucous cells both acidic and neutral in nature.

(6) The salivary gland is worm like, lined by neutral mucus-secreting cells.

(7) The oesophagus is tubular, lined by an epithelium with folds constituting ciliated and mucus-secreting cells.

(8) The style sac secretes the style. The sac communicates with the anterior region of the stomach by a groove. It is lined by thickly ciliated and glandular cells, which secrete the style.

(9) The posterior region of the stomach possesses many folds and acts as the area for sorting, digestion and adsorption of food material. The digestive area is lined by a thick cuticular layer, the gastric shield, against which the style rotates. The inner mucosa of the posterior region is lined with absorptive, digestive and ciliated cells.

(10) In the anterior region lie the openings of the style sac and its epidermal layer consists of ciliated and absorptive cells.

(11) The anterior and posterior regions of the stomach are separated by a muscular typhlosole.

(12) The intestine, originating from the anterior region of the stomach, possesses many ridges and grooves. The epithelial layer is lined by ciliated and secretory cells.

(13) The digestive gland possesses numerous tubules and opens by a pair of ducts to the mid ventral part of the stomach. Digestive cells and absorptive cells, which also function as excretory cells, are present in the digestive gland.

(14) Phagocytic activity by amoebocytes is prevalent in the posterior region of the stomach, digestive gland and intestine.

(15) The rectum has many ridges and grooves, lined by acid and neutral mucus-secreting cells.

(16) C. (C.) cingulata feeds continuously by rasping off the food material from the substratum by the radula. Benthic diatoms and detrital particulate matter serve as food.

(17) The snail makes short feeding migrations.

(18) The snail tolerates starvation upto 30 days without mortality.

(19) The pH of the gut is neutral in the oral cavity, acidic in oesophagus, stomach, style sac, digestive gland

and intestine, but alkaline in the rectum.

(20) The foregut secretes no enzymes. The midgut is the area of high enzyme activity. The digestive gland is the only source of protease and lipase which are, however, weak.

(21) Amylolytic activity is high in the midgut than in the hindgut or digestive glands.

(22) Gut microflora include gelatinolytic, caseinolytic, amylolytic, cellulolytic and lipolytic bacteria, mostly confined to the foregut and the hindgut. These microbes aid in digestion by splitting the complex food particles into simple products, to be acted upon by the native enzymes so as to help effectively in extra- and intra-cellular digestion. Phogocytosis is pronounced in the midgut, digestive gland and the intestinal regions indicating that in C. (C.) cingulata both extra- and intra-cellular digestion play a prominent role.

Table 19. Secretory activity in the alimentary tract of C. (C.) cingulata (Reactions in stains).

Sl. No.	Region	H.H	PAS/Alcian Blue	Acrolein-Schiff	Aldehyde Fuchsine	Remarks
1.	Buccal cavity	Negative	Positive for both	Negative	Negative	Acid and neutral muco polysacchrides
2.	Salivary gland	"	Positive to PAS	"	"	Neutral muco polysacchrides
3.	Oesophagus	"	Positive to both	"	"	Acid and neutral muco polysacchrides
4.	Anterior region of the stomach	Positive	Positive to PAS	Positive	"	Enzymes of glyco-protein nature
5.	Posterior region of the stomach	"	"	"	"	"
6.	Style sac	"	"	"	"	"
7.	Digestive gland	"	"	"	"	"
8.	Intestine	"	"	"	"	"
9.	Rectum	Negative	Positive to both	Negative	"	Acid and neutral muco polysaccharides
10.	Hypobranchial gland	"	"	"	"	"

H.H. = Heidenhein's Haemotoxylin

Table 20. pH in the alimentary tract of *C.* (*C.*) *cingulata*.

Region	pH
Buccal cavity	7.0
Oesophagus	6.8
Stomach	6.2
Style sac	5.9
Digestive gland	6.1
Intestine	6.7
Rectum	7.2

Table 11. Enzyme activity in different regions of the alimentary tract of C. (C.) cingulata.

No.	Substrate	Enzyme	Foregut	Midgut	Digestive gland	Hindgut
Carbohydrases						
1.	Starch	Amylase	-	+++	++	+
2.	Lactose	Lactase	-	+++	++	++
3.	Maltose	Maltase	-	++	++	++
4.	Sucrose	Invertase	-	+	+	-
5.	Glycogen	Glycogenese	-	+	+	-
6.	Dextrose	Dextrase	-	+		-
7.	Filter paper	Cellulase	-	-	-	-
8.	Cotton wool	Cellulase	-	-	-	-
9.	Saw dust	Cellulase	-	-	-	-
10.	Agar agar	Cellulase	-	-	-	-
Proteases						
1.	Gelatin	Protease	-	-	+	-
2.	Gelatin of photofilm	Protease	-	-	+	-
Lipase						
1.	Boiled milk	Lipase	-	-	+	-
2.	Olive oil	Lipase	-	-	+	-

Weak +; Moderate ++; Prominant +++; Absent -

Table 27. Amylase, protease and lipase activity in the alimentary tract of C. (C.) cingulata.

Amylase activity (μ gm glucose/mg tissue/hour)	
Foregut	-
Midgut	8.5
Digestive gland	18.5
Hindgut	14.7
Protease activity (0.2 N NaOH consumed)	
Foregut	-
Midgut	-
Digestive gland	0.3 ml
Hind gut	-
Lipase activity (0.2 N NaOH consumed)	
Foregut	-
Midgut	-
Digestive gland	0.1 ml
Hindgut	-

LIST OF ABBREVIATIONS USED IN FIGURES

ac	:	mucous cells producing acid muco-polysaccharides
an	:	anus
ci	:	cilia
con	:	connective tissue
cpg	:	cerebro-pleural ganglion
cs	:	ciliated cells
cst	:	crystalline style
cu	:	cuticular layer
dfc	:	dorsal food channel
dg	:	digestive gland
dgc	:	digestive cell
dge	:	digestive epithelium
dgo	:	openings of digestive gland
epf	:	epithelial fold
exs	:	excretory spherule
fc	:	food channel
fo	:	folds in stomach wall
fop	:	food particles
glc	:	glandular cells
go	:	gonad
gsh	:	gastric shield
in	:	intestine
ino	:	intestinal opening
j	:	jaw
la	:	lateral tooth
lar	:	lateral ridge
lu	:	lumen
ma_1 ma_2	:	marginal teeth
md	:	median tooth

me	:	mantle edge
mty	:	major typhlosole
mu	:	mucus
muc	:	mucous cells
n	:	nucleus
nmc	:	mucous cells producing neutral muco-polysaccharides
oc	:	oral cavity
od	:	odontophore
oe	:	oesophagus
oeo	:	opening of oesophagus
ovf	:	ovarian follicles
pg	:	pedal ganglion
phg	:	amoebocytes
rd	:	radula
re	:	rectum
rs	:	radular sac
sc	:	secretory cells
seg	:	secretory granules
sg	:	salivary gland
soa	:	sorting area
sr_1	:	smaller ridges
sr_2		
ss	:	style sac
st	:	stomach
stb	:	striated border (brush border)
stw	:	stomach wall
suc	:	supporting cells
ty	:	typhlosole
vfc	:	ventral food channel
vgr	:	ventral groove
vty	:	ventral typhlosole

Fig. 70. Digestive system of C. (C.) cingulata.

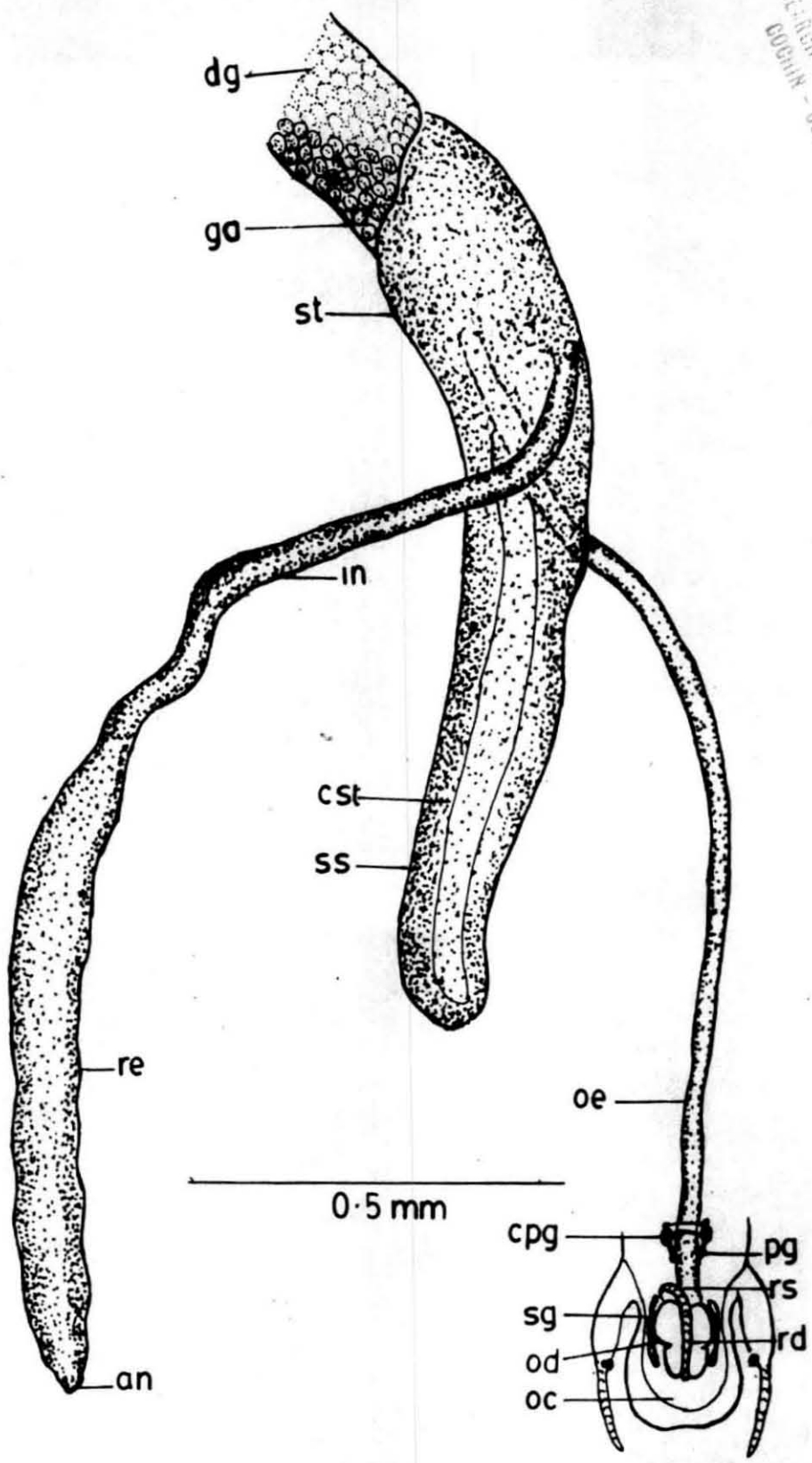


FIG 70

Fig. 71. A) Radular teeth of C. (C.) cingulata.

B) Odontophore of C. (C.) cingulata.

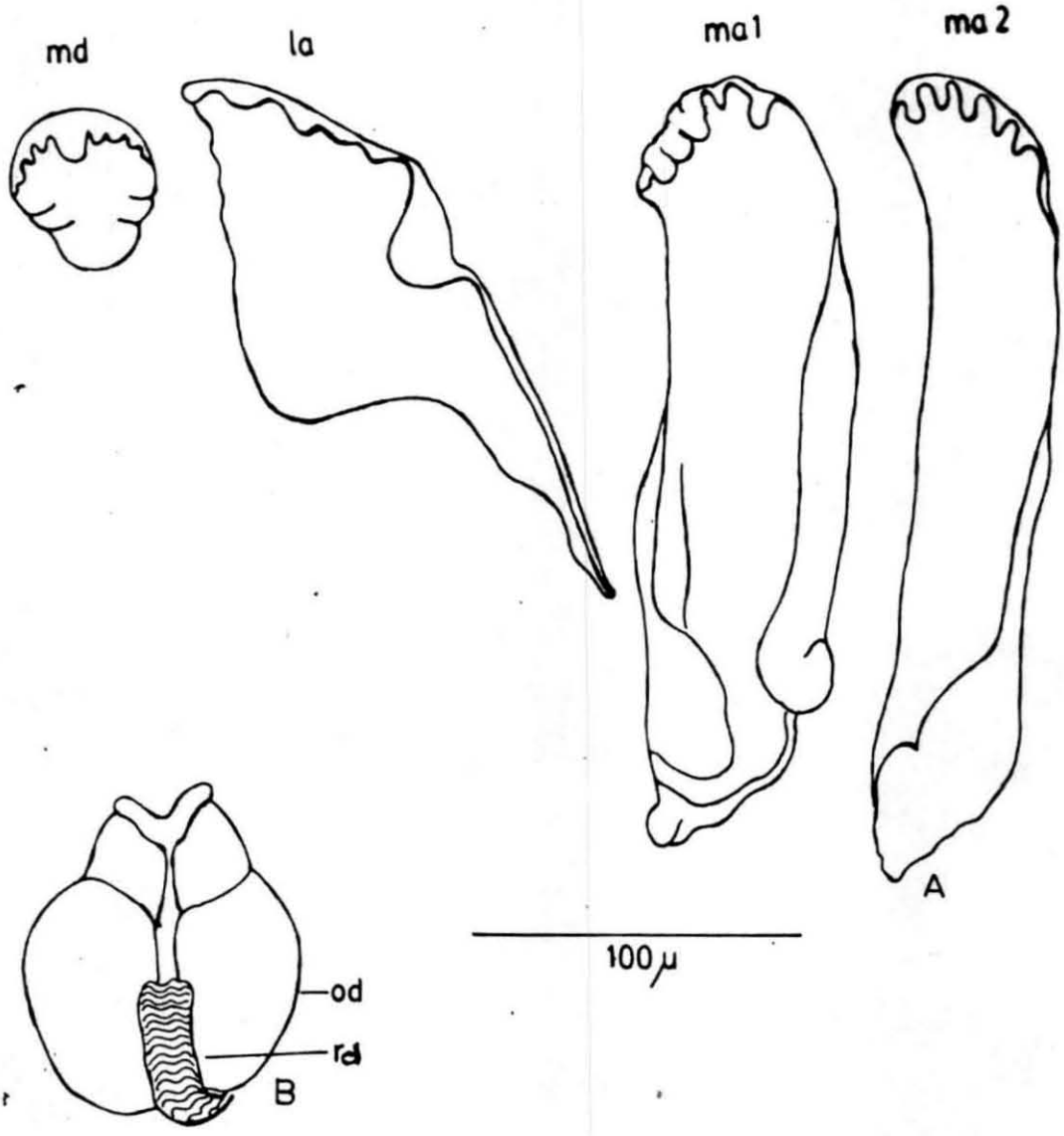


FIG 71

Fig. 72. Stomach of C. (C.) cingulata opened by a dorsal longitudinal cut - arrows indicate direction of ciliary currents.

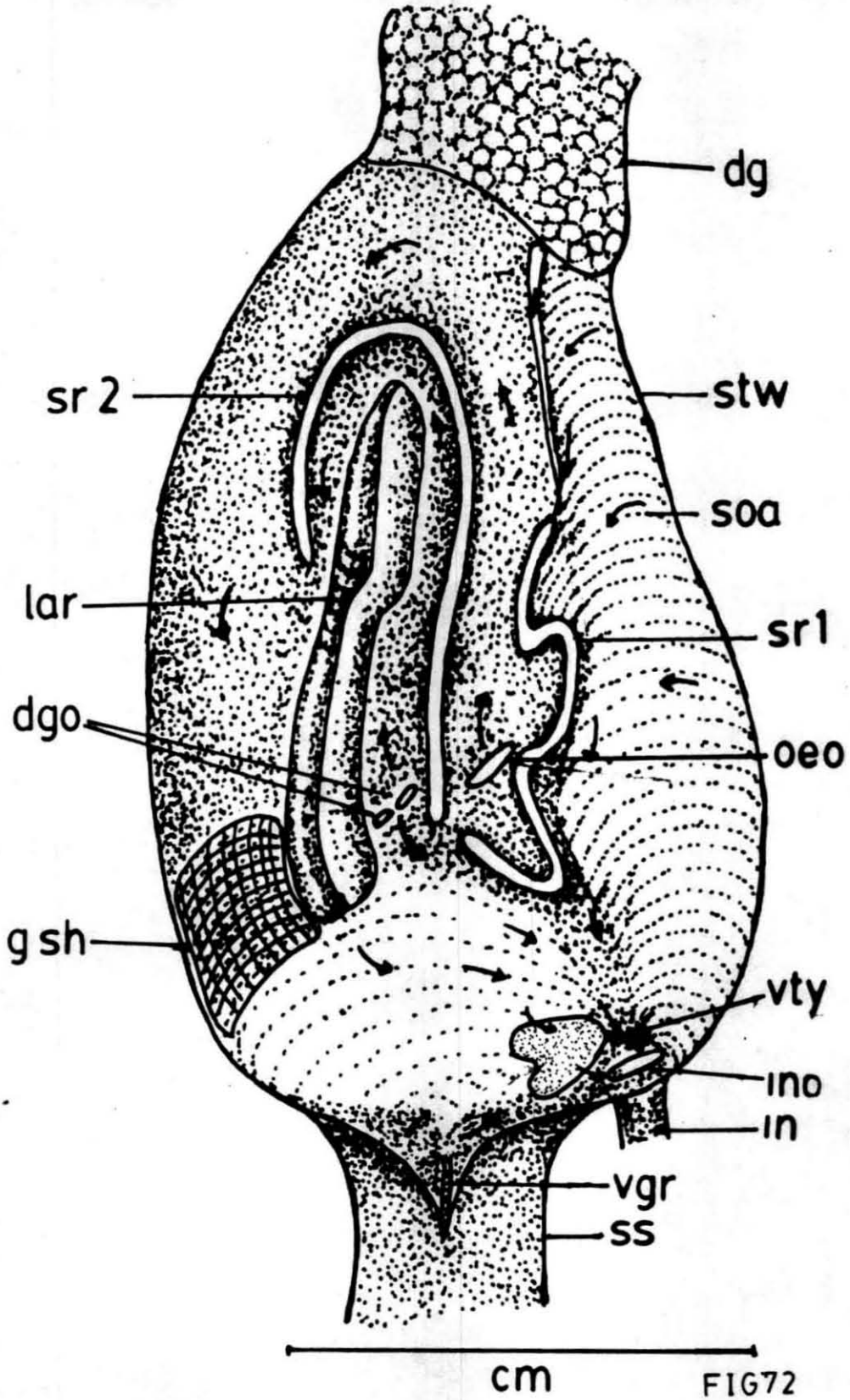


FIG72

Fig. 73. Section through anterior part of oral cavity. Helly - Heidenhain's iron haemotoxylin - 5µ. x300

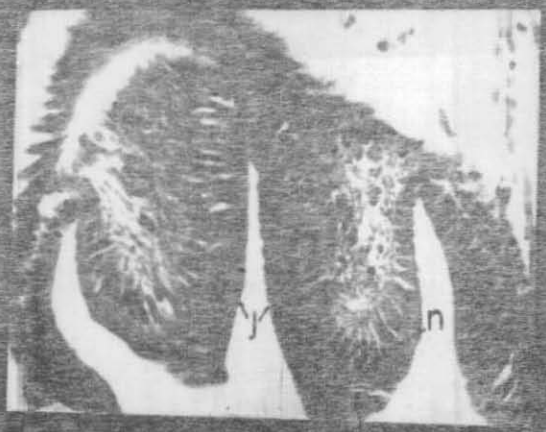
Fig. 74. Section through anterior oesophagus - salivary gland and radular sac. Helly - Weigert's iron haemotoxylin-Liebrich scarlet - 5µ. x150

Fig. 75. Salivary gland - mucus secreting cells with secretions. Helly - PAS - Alcian blue - 5µ. x750

Fig. 76. Wall of oesophagus - acid (darkly stained) and neutral mucopolysaccharides secreting cells with secrections. Helly - PAS - Alcian blue - 5µ. x300

Fig. 77. An enlarged view of a portion of above - mucus secretions are being poured into the food channel. Helly - PAS - Alcian blue - 5µ. x750

Fig. 78. Section through oesophagus - folds in the wall and mucus secreting cells with secretions. Helly - PAS - Alcian blue - 5µ. x300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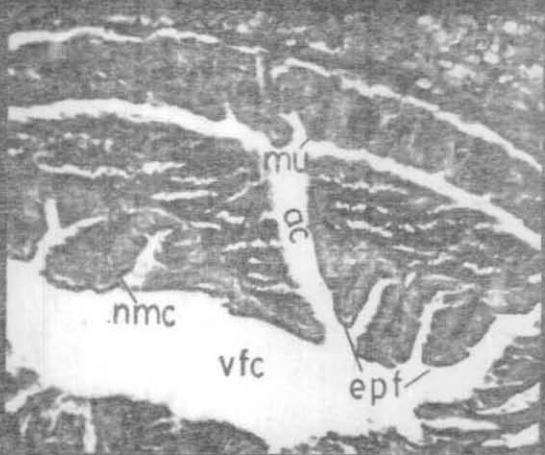
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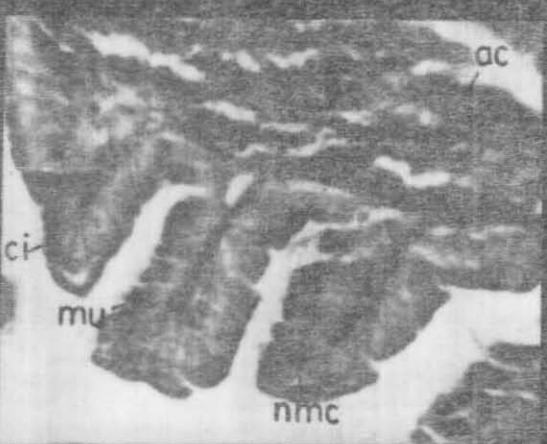
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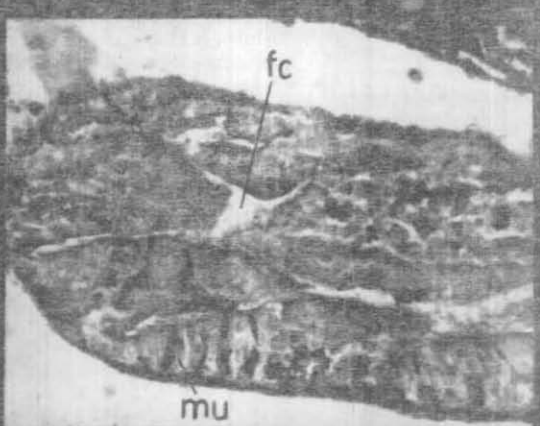
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Fig. 79. T.S. through stomach - sorting area with epithelial foldings. Helly - Weigert's iron haemotoxylin-Biebrich scarlet - 5µ. x75

Fig. 80. T.S. through stomach - sorting area and digestive epithelium. Helly - Weigert's iron haemotoxylin - Biebrich scarlet - 5µ. x150

Fig. 81. A closer view of folds in the sorting area with ciliated cells - cilia in metachronal rhythm. Helly - Heidenhain's iron haemotoxylin - 5µ. x300

Fig. 82. An enlarged view of a fold with ciliated cells. Helly - Heidenhain's iron haemotoxylin - 5µ. x750

Fig. 83. Secretory cells in the stomach wall - cuticular layer over epithelium protecting the walls of high enzymatic activity. Helly - Heidenhain's iron haemotoxylin - 5µ. x300

Fig. 84. Secretory granules in closer view. Helly - Heidenhain's iron haemotoxylin - 5µ. x750


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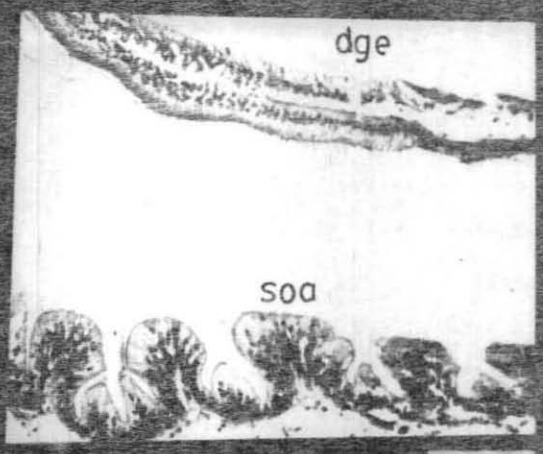
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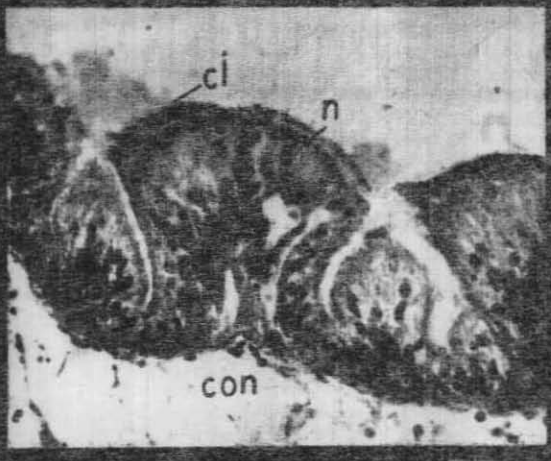
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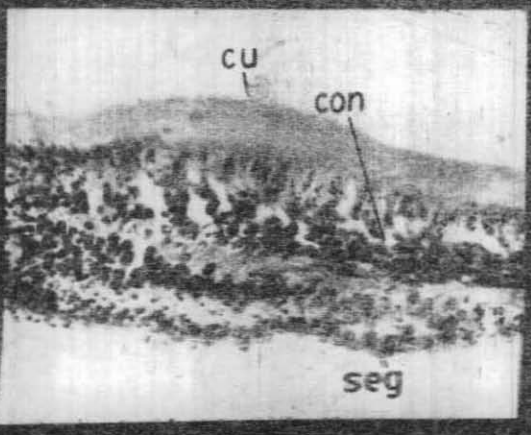
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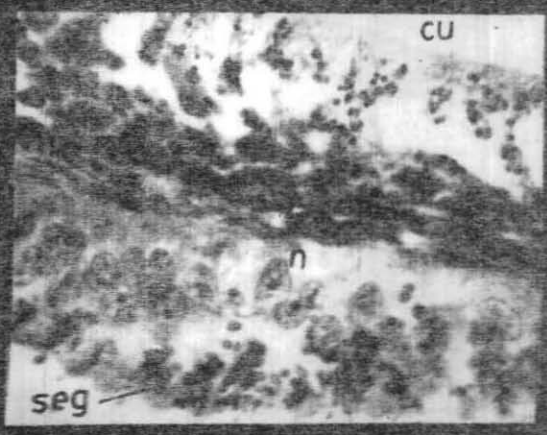
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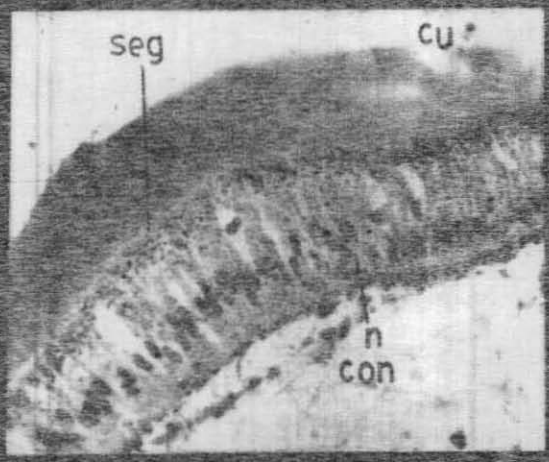
Fig. 85. Secretory cells in the stomach with zymogen granules at top and large nuclei at base - cuticular layer evident. Helly - Heidenhain's iron haemotoxylin - 5µ. x300

Fig. 86. An enlarged view of the above - basal large nuclei and fine secretory granules clearly visible. Helly - Heidenhain's iron haemotoxylin - 5µ. x750

Fig. 87. Absorptive cells of stomach wall - brush (striated) border over the cells clear. Helly - PAS - Alcian blue - 5µ. x750

Fig. 88. Absorption of fine food particles by stomach wall - phagocytic activity evident - empty and food laden amoebocytes visible. Helly - Heidenhain's iron haemotoxylin - 5µ. x750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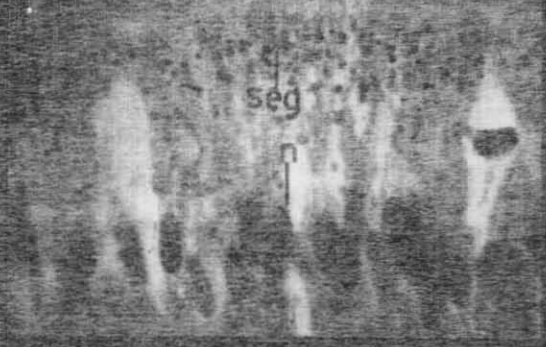
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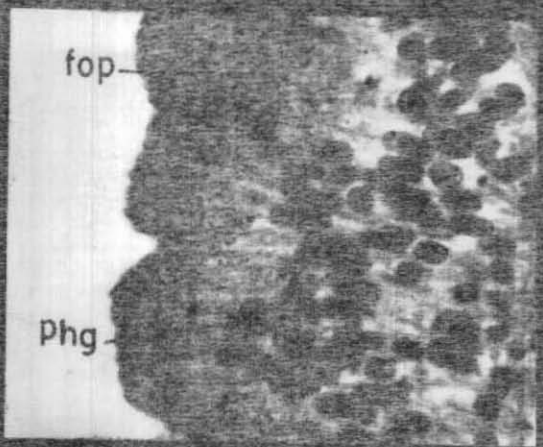
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Fig. 89. Absorption and secretion in the stomach - proteinecious secretions (granules, deep red in colour) and food particles (fine dark granules) visible. Helly - Acrolein Schiff - 5µ. x750

Fig. 90. Crystalline style in style sac - ciliated area, glandular area and ventral groove evident. Masson's trichrome - Weigert's iron haemotoxylin - Xylidine panceau-chlorantine fast red-aniline blue - 5µ. x75

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Fig. 91. Ciliated cells of style sac - uniformly sized cilia and basal nuclei evident. Helly - Masson's trichrome - 5µ. x300

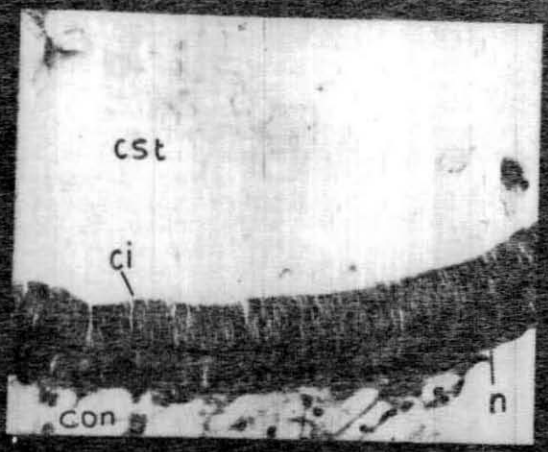
Fig. 92. Glandular cells of style sac. Helly - Masson's trichrome - 5µ. x300

Fig. 93. Ventral groove and its connection with the style sac. Helly - Masson's trichrome - 5µ. x300

Fig. 94. Tubules of digestive gland - secretory cells, excretory spherules and digestive cells seen. Helly - Weigert's iron haemotoxylin - Biebrich scarlet - 5µ. x300

Fig. 95. A closer view of the above. Helly - Weigert's iron haemotoxylin - Biebrich scarlet - 5µ. x750

Fig. 96. Tubule of digestive gland - excretory spherule being dropped into lumen. Helly - Heidenhain's iron haemotoxylin - 5µ. x750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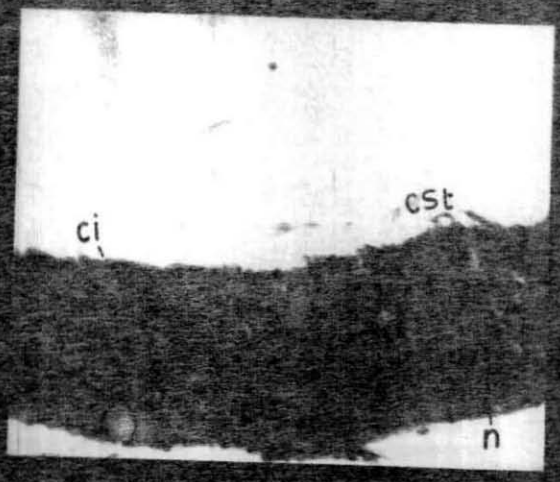
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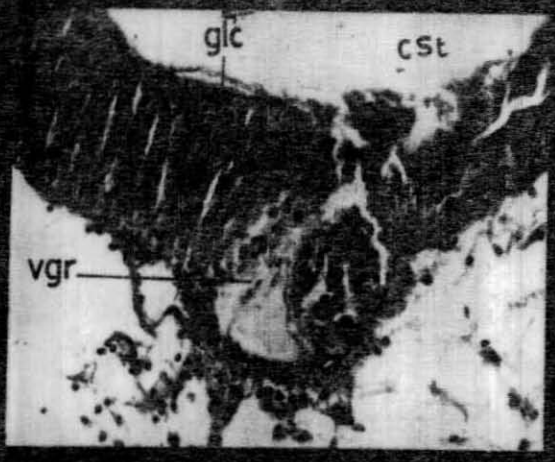
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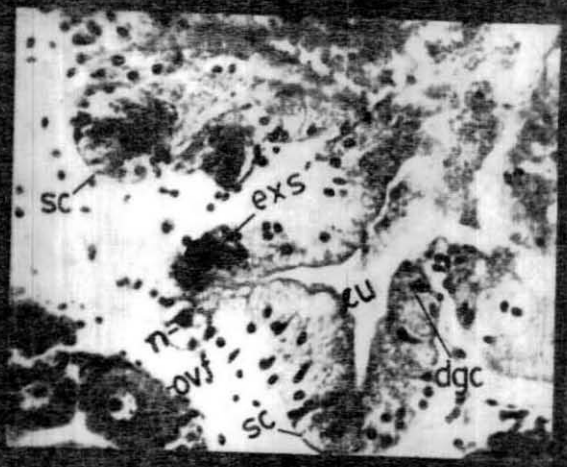
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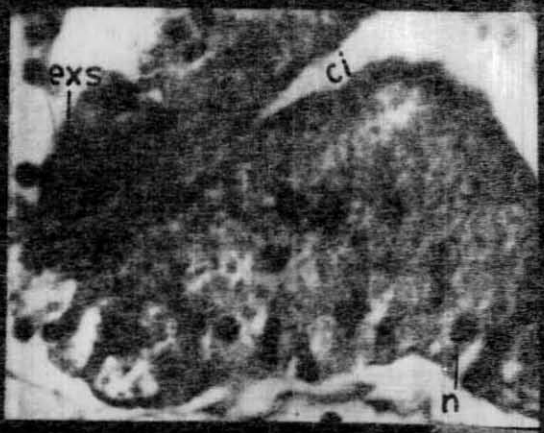
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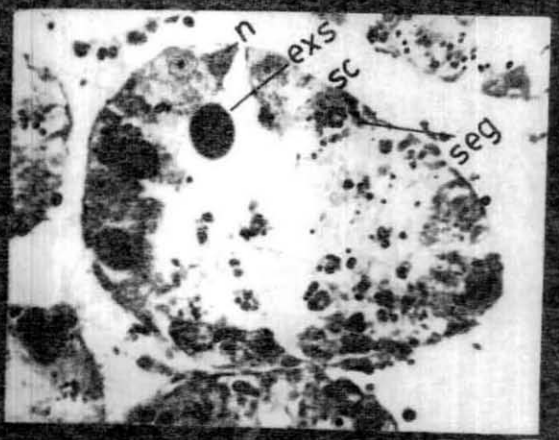
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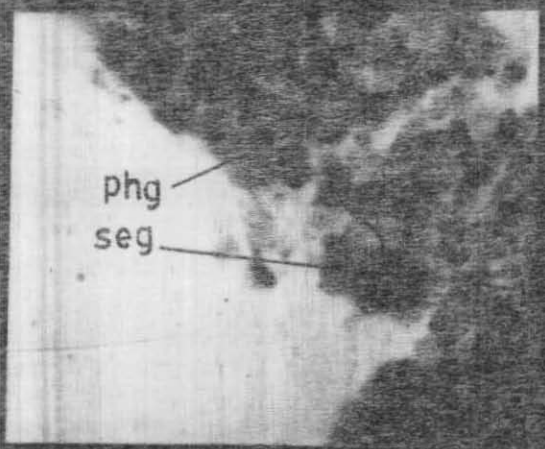
Fig. 97. An enlarged view of a tubule of digestive gland - secretory granules and phagocytes visible. Helly - Heidenhain's iron haemotoxylin - 5μ. x750

Fig. 98. T.S. through intestine (entire view) - major and smaller typhlosoles evident. Helly - Weigert's iron haemotoxylin - Biebrich scarlet - 5μ. x150

Fig. 99. Ciliated cells in the intestinal wall. Helly - Weigert's iron haemotoxylin - Biebrich scarlet - 5μ. x750

Fig.100. A closer view of intestinal wall with secretions. Helly - Heidenhain's iron haemotoxylin - 5μ. x300

Fig.101. Secretory cells in the intestinal wall - zymogen granules visible. Helly - Heidenhain's iron haemotoxylin - 5μ. x750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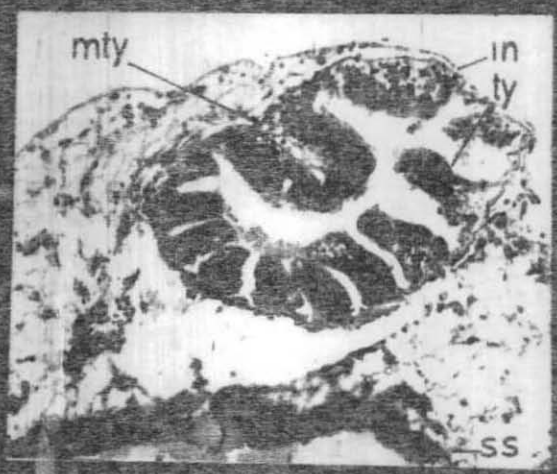
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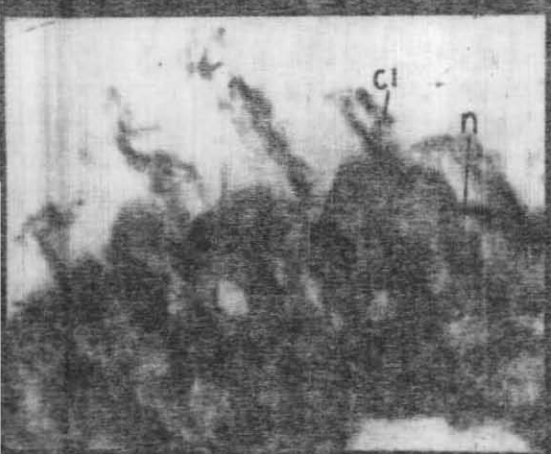
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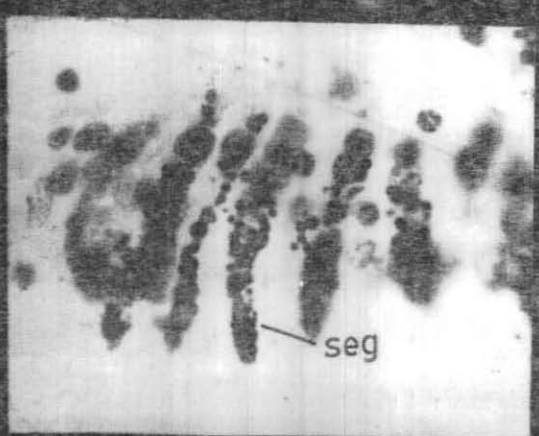
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Fig. 102. Secretions in the intestinal wall - positive to Acrolein Schiff indicating the enzymes. Helly - Acrolein Schiff - 5μ. x750

Fig. 103. Secretions in the intestinal wall - positive to PAS indicating glycoprotein nature of the enzymes. Helly - PAS - Alcian blue - 5μ. x750

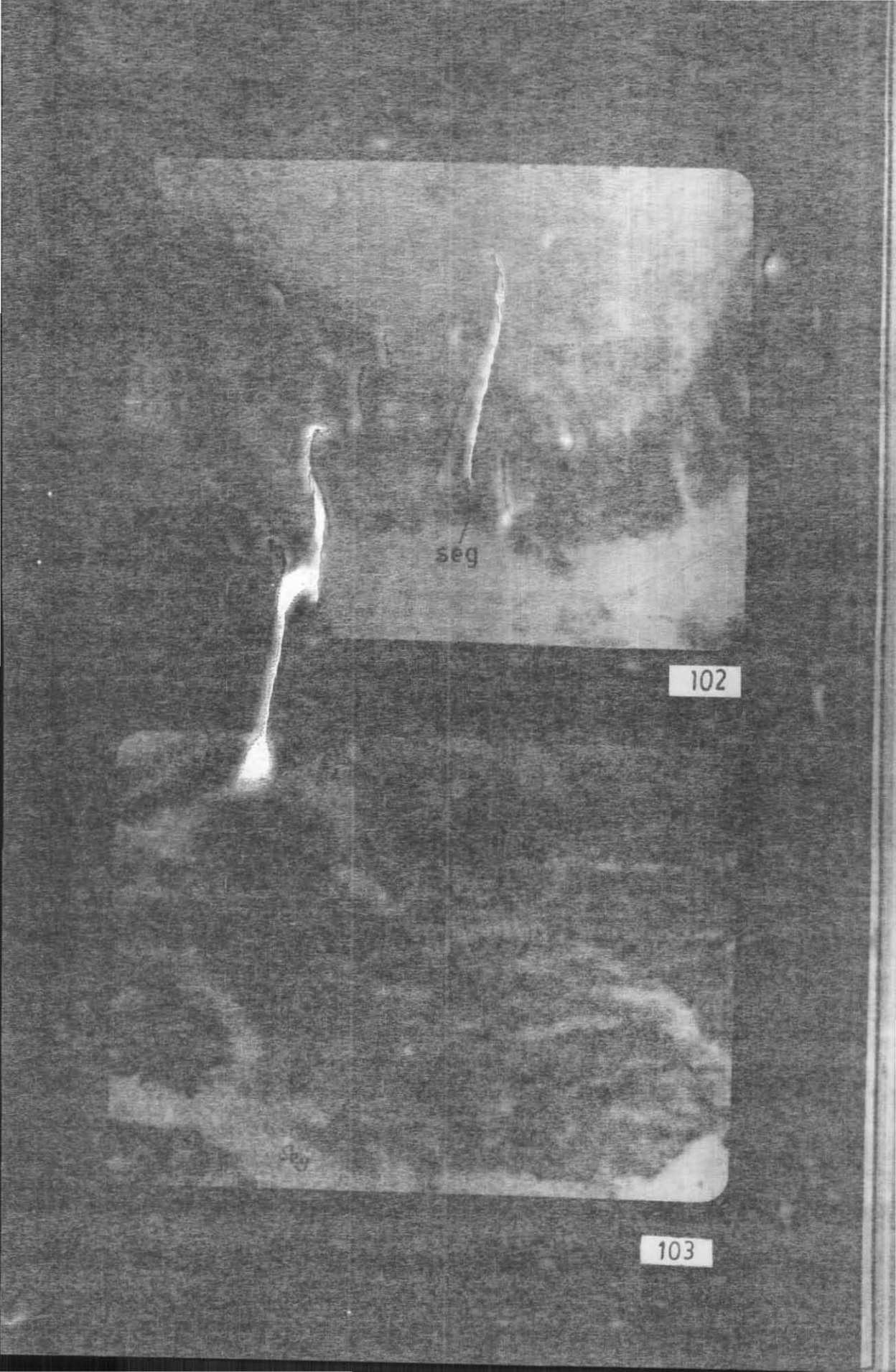
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Fig. 104. Rectum with anus. Helly - Heidenhain's iron haemotoxylin - 5µ. x75

Fig. 105. Ciliated and secretory cells of the rectal wall. Helly - Heidenhain's iron haemotoxylin - 5µ. x750

Fig. 106. An enlarged view of the hypobranchial gland showing mucus secretions. Helly - PAS - Alcian blue - 5µ. x750

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Fig. 107. Colony forming units / gm (log) of different types of bacteria in water, sediment and gut of C. (C.) cingulata.

Dg : Digestive gland
Fg : Foregut
Hg : Hindgut
Mg : Midgut
S : Sediment
TVC : Total viable count
W : Water

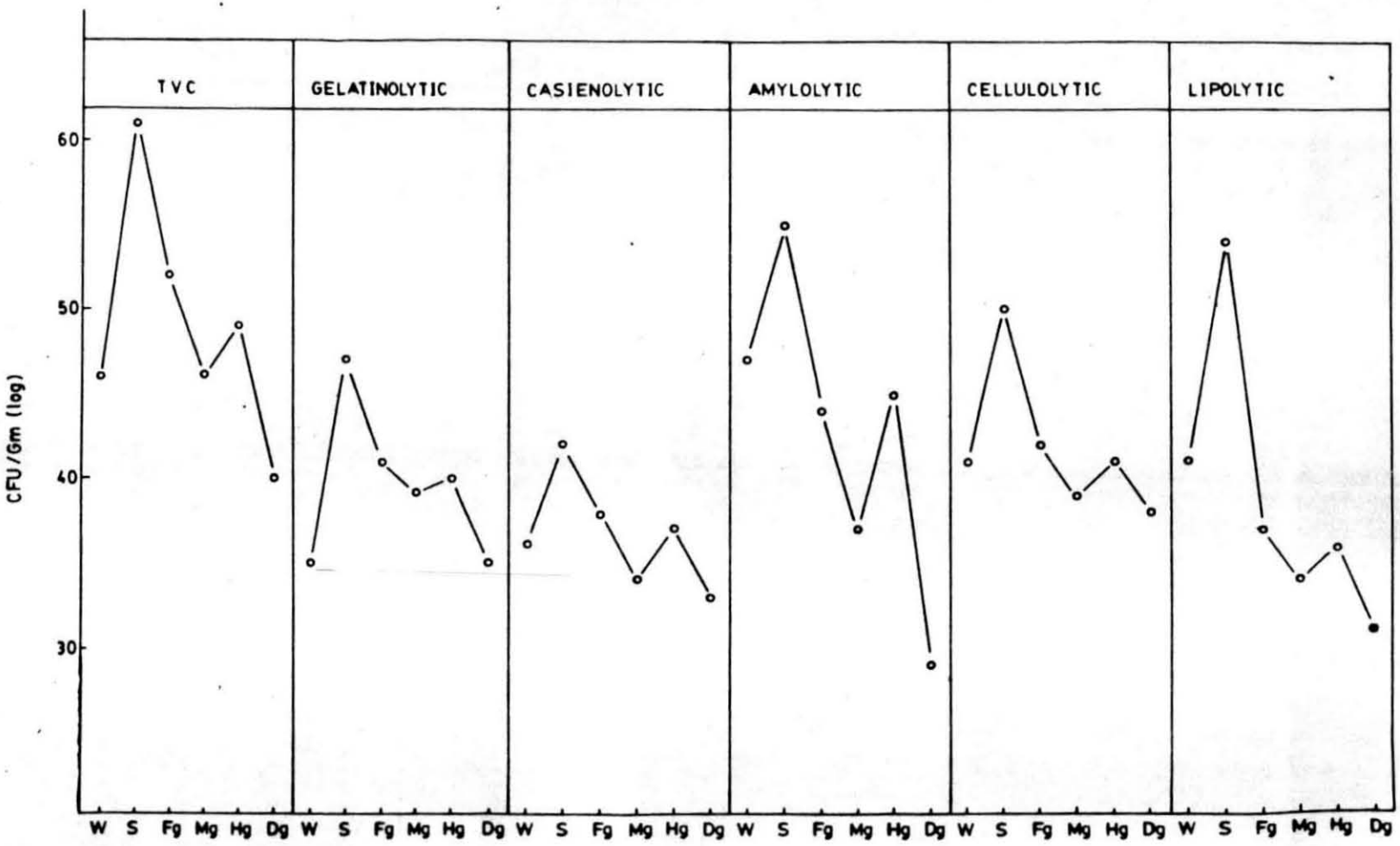
TVC
GELATINOLYTIC
CASIENOLYTIC
AMYLOLYTIC
CELLULOLYTIC
LIPOLYTIC
CFU/Gm (log)
60
50
40
30
W S Fg Mg Hg Dg

FIG 107

6. REPRODUCTION AND LIFE HISTORY

6.1 INTRODUCTION

The reproductive system as well as the reproductive habits and cycles of prosobranchs have been summarised by Fretter and Graham (1962, '64), Hyman (1967), Morton (1967) and Fretter (1984); the gametogenesis of molluscs by Fretter and Graham (1962, '64), the morphology of the gametes by Fretter (1984), the process of fertilization and subsequent development of egg leading to the formation of zygote by Raven (1964), Lange (1983) and Fretter (1984), cleavage, the early development and formation of germ layers by Raven (1958, '64), Verdank (1979) and Verdank and Van den Biggelaar (1983) and organogenesis by Moor (1983). Significance of torsion among the gastropods was discussed by Lever (1979). Planktonic veligers of prosobranchs, duration of swimming stage, development, behaviour and ecology of larvae have been reviewed by Fretter (1984).

Information on the reproductive systems of potamidids is available from the works of Bright (1960) on Cerithidea californica, and of Swaminathan (1961) on Telescopium telescopium. Spawning and larval development of the latter have been studied by Ramamoorthy and Natarajan (1973). Egg mass of Cerithidea (Cerithideopsilla) cingulata

was described by Panikkar and Aiyer (1939) and the developmental stages by Natarajan (1958). Habe (1957) described the veligers of C. djedjariensis and C. rhizophorum.

A comprehensive study on reproductive system, maturation, sex ratio, pairing, spawning, larval development and settlement of spats in C. (C.) cingulata was undertaken presently since available information was patchy and the results are presented in this chapter.

6.2 MATERIAL AND METHODS

Samples of C. (C.) cingulata were collected from three sampling sites as described earlier. The snails were brought to the laboratory, measured and then removed from the shell. The sex and the stage of maturity of the gonad, were noted from the colour differences and smears of gonads. Smears of spermatozoa were made, using the dry-smear techniques (unstained) and with Ehrlich's haemotoxylin stain as suggested by Franzen (1956). Histological preparations were made of the gonads preserved in Zenker's fluid. 5 and 8 μ thick sections were made and stained with

monochrome, dichrome and trichrome stains. (Details of histological preparations are given in Chapter 5 - Digestive organs and digestion).

Size at first maturity was calculated by arranging the percentage of mature specimens in each length. The shell length at which 50% of the snails were found to be with either of the gonads was considered as the minimum size at first maturity.

An index was obtained by the formula evolved by LeCren (1951), which is,

$$\frac{\text{Observed Weight}}{\text{Calculated Weight}}$$

for the mean length in a month.

Pairing and spawning behaviours were observed in the field as the snail did not readily pair or spawn in the laboratory. Egg masses collected from the field, opposite the biological station were reared at room temperature, in 500 ml beakers containing filtered estuarine water. No special feeding or aeration was provided. The water was changed twice daily and only the larvae floating near the surface were transferred to the new container. The salinity of water was 32‰ and the temperature 29±1°C. The larvae could be observed upto 15th day after hatching by which time all of them settled as spat. Further studies on spat

were carried out by collecting them from sediments. All the figures were drawn using the mirror type camera lucida, at table-top magnification.

6.3 RESULTS

C. (C.) cingulata is dioecious like other potamidids, C. californica (Bright, 1960) and T. telescopium (Swaminathan, 1961). Though shell morphology does not indicate any sexual dimorphism, the adults can be distinguished from juveniles by a hump in the body whorl. Ripe and spawning females can be distinguished from others by the swollen right side of the foot appearing bright yellow. Though Bright (1960) reported the presence of a penis in the males of C. californica, no such organ could be found in C. (C.) cingulata.

6.3.1 Male reproductive system

The male reproductive system of C. (C.) cingulata contains (1)the testis, (2)vas deferens, (3)prostate gland,

(4)the lateral and median lamellae and (5)the ciliated ridge (Fig. 108 A).

The testis is yellow, large and unpaired. It is embedded in the digestive gland except for a narrow strip on each side of the vas deferens on the columellar side. On the surface, the testis is lobate with numerous branched tubular follicles. These tiny tubules anastamose to form the vasa efferentia which connect the testis with the tubular vas deferens. The latter is unpaired and runs from the penultimate whorl along the columellar side of the coiled digestive gland, until it reaches the anterior ventral portion of the style sac in the stomach. It then curves abruptly before it terminates at a pocket-like structure found in the open tract, where the median lamina folds over the lateral lamina. At this point, the sperm duct is dilated, glandular and acts as the prostate gland (Houbrick, 1973). Beyond the prostate, the genital groove extends forward as 2 broad laminae fused dorsally and to the mantle. The ventral margins of the laminae are free forming a channel, which communicates freely with the mantle cavity. Thus, the male gametes are discharged freely into the general mantle cavity. The epithelial lining of the inner wall in the posterior part of the laminae has numerous folds, which are ciliated and glandular.

Histology

The testis contains numerous follicles with highly folded convoluted germinal epithelium (Fig.109 & 110). The primary spermatocytes could be seen in large numbers with prominent nucleoli. Cellular division involving reduction division takes place in the formation of sperms (Fig.111-113).

Two types of sperms are met with in C. (C.) cingulata, as in many members of prosobranchs. The eupyrene sperms are 165 to 200 μ long, while the multiflagellated apyrene sperms are 150 to 170 μ long (Fig.108.C & D). The eupyrene sperm has a broad head with an ovoid nucleus, capped by an acrosome, a middle piece and a long flagellum; the middle piece is lacking in the apyrene sperm. Both move very actively in thin film of water as seen under the microscope.

The interior layer of the sperm duct is ciliated. The cells which occupy the inner layers of the male genital groove are also ciliated. The other two layers of cells are the columnar nucleated cells and the square indistinctly differentiated cells. Sperms lie packed in the seminal grooves in mature specimens. Here the albuminous viscid fluid of the prostate gland mixes with the sperms before the spermatophore is formed.

6.3.2 Female reproductive system

The female reproductive system comprises the ovary and oviduct, and an open pallial oviduct (medial and lateral laminae, seminal receptacle, albumen gland, capsular gland and the sperm collecting gutter)(Fig.108.B).

The ovary, appears creamy in fully ripe stage and envelopes the digestive gland superficially except on the columellar side. The oviduct is a long thin tube and is connected to ovary by many tubules. The oviduct confluences with the open pallial gonoduct near the stomach. The latter possesses two laminae, the median and lateral, as in the male, and communicates freely with the mantle cavity.

Both the laminae are larger, more glandular and have a thinner, non-glandular portion along the median edge of the laminae. Inside this non-glandular portion runs a ciliated tube, which confluences with the sperm-collecting-pouch posteriorly and opens to a slit which is short and shallow anteriorly. This slit is termed as the sperm collecting gutter.

The posterior portion of the glandular laminae serves as the albumen gland and the anterior region as the capsular gland. Inside the sperm collecting pouch is

embedded in the wall of the inner portion of medial laminae, a glandular area which forms a flap. Under this flap is a tiny opening, leading through the wall of the laminae into the lumen of the posterior end of the pallial gonoduct. This area is referred to as the seminal receptacle, where the sperms are stored until fertilization. Opposite the opening of the closed oviduct, on the bodywall, is a heavily ciliated region, which is the area of fertilization. Eggs leave the mantle cavity and reach the exterior along a groove formed by the foot. In a spawning specimen this area appears swollen and bright yellow as already mentioned.

Histology

Sections of the ovary show an outer connective tissue investment and an inner germinal epithelium (Fig.114 & 115). Different stages of maturation of oocytes and ova can be seen in the ovary simultaneously. The early primary oocytes have large nuclei with prominent nucleoli. The cytoplasm is basiphil. Further growth and maturation results in the enlargement of nucleus into a germinal vesicle. Yolk granules are distributed in the cytoplasm and fill up the entire cytoplasmic area (Fig.116-118).

The oviduct is circular, with ciliated columnar epithelial cells. The epithelial layer of the oviduccal

groove possesses cilia. The cells are not uniform and the shape of the nucleus also vary.

Albuman and capsular glands possess cells of irregular shape, with small and spherical nuclei. The epithelium is formed by columnar cells interrupted here and there by large cells.

Ova, formed in the ovary are passed to the pallial open duct by ciliary movement. These ova are fertilised by the sperms, which move from sperm collecting pouch via the seminal receptacle, whose opening lies closer to the opening of the oviduct. Fertilization takes place at this spot and the zygote passes through albumen and capsular glands, which secrete albumen and the capsule around the zygote. The eggs are then conveyed to the pedal groove, which secretes a mucus-covering over the capsulated eggs and releases them in the furrow formed in the soft mud, by the pressure of the foot.

The sperms enter the mantle cavity through the inhalent current, reach the sperm collecting gutter and move posteriorly, directed by a ciliary movement, to the sperm collecting pouch, from where the sperms pass to the spot of fertilization through the seminal receptacle.

6.3.3 Stages of maturity

Based on colour differentiation and cellular detail, the following stages of maturity could be distinguished, as stated already by Williams (1964a,b) and Ward (1966b).

Developing

The testis, bright yellow, is covered by a membrane. Small white areas on the surface represent the seminiferous tubules. The ovary is pale bluish during maturation. The ovarian tissue is composed of connective tissue, oogonia and developing oocytes.

Mature:

The mature testis is bright yellow and under slight pressure, a white pack of sperms can be seen to ooze out of the testis. The sperms, both eupyrene and apyrene, are well discernible.

The mature ovary is creamy in colour and swollen. The grown eggs are lightly packed and the mature eggs have a thin gelatinous coat.

Spent:

The testis appears brownish yellow and the connective tissue was observed to increase while there was

a decrease in the number of spermatozoa.

The spent female has a pale creamy ovary. There is considerable reduction in the number of eggs when compared to the former stage of maturity. Connective tissue increases considerably and the effect of spawning is more evidenced in the case of ovary than in the testis.

Month-wise percentage occurrence of various stages of maturity among male and female specimens of C. (C.) cingulata is shown in Table 23 & 24 respectively. All three stages of maturity were present during all the months which indicates a prolonged spawning period.

Among males, mature individuals dominated during all the months, but greater predominance seems to be from January to September. Maturing specimens were common from December to March in 1982-'83, while spent individuals were more from July to December in 1983.

In the case of female, mature specimens were dominant over maturing and spent stages during most part of the year particularly from January to September. Maturing specimens were more during January, April and May in 1983, while specimens in spent condition were recorded in higher percentage in December of both the years.

6.3.4 Size at first maturity

Percentage occurrence of indeterminate, male and female specimens in various length groups is given in Table 25, which indicates that 50% of the individuals were with either of the gonad from the shell length of 16 mm onwards. Therefore the minimum size at first maturity in C. (C.) cingulata can be assigned as 16 mm, for both male and female. From growth studies (vide Chapter 4), it was found that 16 mm size was attained in 15 months by C. (C.) cingulata, indicating that it attains maturity during the second year of life. Associated with maturity of the gonad, a hump like expansion on the body whorl of the shell develops on the right side.

6.3.5 Sex ratio

Sex ratio in monthly samples of C. (C.) cingulata is shown in Table 26. During 24 months, male dominated over female only twice (June of 1983 and '84), whereas the sexes were equal in October 1982 and August 1984. On testing for homogenity (by Chi-square test), it was found that the ratio was consistantly 1:1.

Sex ratio in different size groups also revealed

the dominance of female over male in most of the groups except in 12, 25, 27 and 33 mm size groups (Table 27). However, the test for homogenity indicated 1:1 ratio in all size groups excepting five (26, 27, 28, 29 and 31 mm).

6.3.6 Kn Index

Relative condition factor (Kn) reflects the physiological condition of the animals. During spawning, the snail undergoes physiological stress which is reflected in variations of the Index. The values of Kn for different months (presented in Table 28) are mostly around 1 with no significant variations.

6.3.7 Parasitation

During the present investigation, some specimens of C. (C.) cingulata were observed to be infested with cercariae of trematodes which turned the ovary into bright yellow like a testis. Such parasitic castration was observed earlier by Houbrick (1973) and by Gannon (1975) in the case of Cerithium. Percentage occurrence of such castrated snails is given in Table 29. Highest of 11.8% could be noted in October 1983.

6.3.8 Mating

Pairing of specimens could be observed in the field (Fig. 4A) in all three stations from January onwards until September. However, the snail did not respond to this sexual activity during confinement in the laboratory. The stimuli which bring the male and female together are yet to be understood. During the nuptial act, the male clings to the female close to the right pallial side. Slight disturbances do not affect pairing and their hold is stronger to the extent that both of them could be lifted off the ground. On slight separation of the pairing individuals, a white jelly mass, the spermatophore being transferred from male to the female, could be observed. This spermatophore is carried into the mantle cavity of female by the inhalent current. On disintegration of this, the sperms pass to the right side of the mantle cavity and are taken along the mantle floor to the oviduccal groove, where fertilisation takes place. The sperms are moved into the sperm collecting gutter by ciliary action.

Pairing was observed to extend for more than an hour. Such specimens were observed during all the times of the day and also in the early part of night.

During pairing, both the individuals remain

inactive. Position of male and female was observed to differ, but the male was usually attached to the left anterior side of the female shell so that its propodium made contact with the edge of the female's foot or mantle edge. Size difference was common among the pairing individuals.

6.3.9 Oviposition

Spawning in C. (C.) cingulata was observed in the field on many occasions from January to September. Spawning females were found outside the water edge also. During oviposition, the females firmly pressed the soft substratum to make a small narrow gutter and laid the eggs in gelatinous mass which was flat and broad (Fig.120). But soon after laying, this egg mass coiled into tube by wave action or by shrinkage on exposure. Short jerky movements and turns of the foot occurred frequently as the eggs, embedded in the filament, emerged. The filament moved slowly from the right side of the mantle cavity near the exhalent siphon and proceeded to the right side of the foot to the furrow in the modified, swollen, bright yellow propodium. The radula continuously rasped the substratum, probably altering the

surface for the laying of eggs. Time taken for oviposition varied from a few minutes upto three hours. Even a slight disturbance stoped the snail from laying eggs and this often resulted in partial spawning. Maximum length of the eggmass recorded during the period of observation was 232 mm laid by a snail with 22.5 mm shell length (Fig.121). The width of the eggmass varied from 1 mm to 2 mm. The largest number of eggs recorded presently in an egg mass of 232 mm in length was 17,456. The egg mass was generally covered by detritus, sand and other particles and also infested by ciliates, Navicula and nematodes. However none of them were observed to penetrate any egg capsule.

Egg massess were observed more commonly from Sites I and III and only occasionally at Site II. The number of egg masses recorded is presented in Table 30. It could be seen that the number of egg masses was more during 1983-'84 compared to 1982-'83. Maximum number of egg masses was recorded from February to April (late postmonsoon and early summer). Highest number of egg masses recorded ($28/m^2$) was just the same as the records of Panikkar and Aiyer (1939) for this species from the Adyar estuary, Madras (20/sq.yard).

6.3.10 Early development

Individual egg of C. (C.) cingulata has already been described by Natarajan (1958) for this species. Enlarged views of a portion of egg mass are given in Fig.122.A & B. The egg was pale yellowish due to presence of yolk. The tough hyaline capsule, has a diameter of 160 μ. Surrounded by albumen, the zygote measured around 115 μ heavily yolked and the nucleus was not visible (Fig.122.C). The eggs were telolecithal and were arranged in rows in the egg mass, agglutinised by sand particles.

Twenty or thirty minutes after laying, the first movement of the zygote could be observed, when the protruberence of the polar lobe was formed on the vegetal side (Fig.122.D). It took about 10 minutes to form a full bulge and the polar lobe disappeared at the formation of the first polar body in the opposite pole (the animal pole) (Fig.122.E). The cell cleaved slowly and the 2-celled stage was attained in about 60 minutes (Fig.122.F & G), after which the division was unequal and spiral. Later cleavages led to a bunch of cells with prominent vegetal blastomeres (Figs.122.H, I & J). Stages of subsequent cleavages were difficult to follow because of aggregation of cells into a thick dark mass. However, a typical sterroblastula was present prior

to gastrulation (Fig.122.K). The later process was brought about by epibolic growth of the micromeres over the macromeres. Extremely rapid proliferation of micromeres completely covered the macromeres (Fig.122.L & M).

The appearance of extensive ciliation, and rotation of embryo within the egg, marked the attainment of trochophore stage, after 10 hours of spawning (Figs.122.N & 123.A). Conspicuous cilia lined the dorsal and ventral lips and the whole prototrochal region. The embryo measured about 140 μ at this stage and rotated within the albuminous fluid in all directions.

Elongation of the embryo and the formation of shell glands indicated the beginning of the veliger stage (Fig.123.B-F). An illdefined stomadeum was evident just above the pedal analge. Cells in the apical region appeared much smaller in contrast to the large yolked cells of digestive analge.

By 24 hours, the embryo developed prominent velar lobes, a better defined foot, a cup like protoconch and the digestive gland (Fig.123.G).

The embryo reached the final phase of the prehatching stage after 36 hours, in which basic functional organs needed by planktonic veligers are formed (Fig.123.H).

The mouth and oesophagus were functional. Yolk remained in the posterior part of stomach and digestive gland, and this gave a yellowish appearance to the developing embryo. As indicated by the veliger's reaction to its environment, all basic nervous and sensory units were functional.

The protoconch was pitted, with thin striations visible near the beak. The body retracted into the shell on external disturbance. The veliger had well developed eyes, tentacles and a rhythmically pulsating larval heart, just beneath the shell on the right side of the mantle cavity. A well-defined operculum extended beyond the metapodium. Bilobed velum was strongly ciliated and the embryo revolved within the egg case for another 12 hours. The embryo measured about 145 μ at this stage.

Hatching of the planktotrophic veliger took place 48 hours after spawning. Davies(1967), suggested that preliminary softening or liquifying of the egg membrane was done by enzymes secreted by the veliger, but final emergence in all instances was by physical struggle. Buckland-Nicks et al. (1973) felt that shell sculpture also helped in breaking the egg membrane. All the eggs in the egg mass did not hatch out simultaneously, because of differences in stages of development. This was due to the difference in the timing of egg-laying.

6.3.11 Planktotrophic larva

On hatching, the veliger measured around 165 µ. The muscular foot was pale yellow and the operculum transparent. Bilobed velum had two rows of cilia, the outer row being larger. The larvae swam with powerful strokes of velar lobes (Fig.123.I).

The eyes, black in colour, were at the base of the tentacles. A statocyst was present at the base of the foot. A pulsating heart was seen on the right side of the mantle cavity. The digestive gland was lobed and appeared yellow due to the presence of yolk. The soft parts were completely withdrawn into the shell, to be closed by the operculum on disturbance.

The transparent protoconch was lightly pitted and striations could be noted on the body whorl. The shell was strongly beaked where lines of growth are clearly visible (Fig.123.J).

Gradual increase in the size of shell and a reduction in yolk content of the digestive gland were observed in the subsequent days. From the second to the fourth day, neither shell sculpture nor soft parts showed much variations from the hatched out larvae (Fig.123.K,L & M). However, on the fifth day, the shell had two whorls and

measured about 190 μ (Fig.123.N). The tentacles enlarged in size and there appeared to be a slight reduction in the velar lobes. By seven days, the striations on the body whorl got thickened and the larva measured 195 μ (Fig.123.O). The 9- and 10-days old veliger had 2½ whorls with the body whorl, showing similarity with the adults in having an outer lip with thickened striations (Figs.123.P, 124.A & B). The striations became still stronger when the larva settled near the bottom and crawled, dragging the shell on the bottom with the help of foot. This "Swim-Crawl" or "search" stage marked the retardation of velar lobes still further. Shells of 12-, 13- and 15-days old veligers had 2½ whorls and sculptures similar to that of adult individuals. The shell of 15-days old veliger measured 270 μ. The shell transparency was reduced. Velum was reduced and the foot was massive. The veliger crawled most of the time, but was swimming only now and then. The tentacles became larger and a spherical operculum was clearly visible. Further rearing of the veliger in the laboratory was not possible because of heavy mortality due to ciliate infection and also due to the non-availability of suitable feed for the larvae.

Monitoring of the veligers of C. (C.) cingulata in the plankton collections of the Vellar estuary was

carried out for two years and the results are presented in Table 30. The veligers were present in the plankton from January to October, coinciding with the spawning period of the species. Highest number was recorded in April 1984 and the lowest in October 1982.

6.3.12 Spats

The size of the smallest spat of C. (C.) cingulata collected from the mud samples of the Vellar estuary was 300 μ with 2½ whorls resembling the 15-day old veliger (Fig.125.A & B). Examination of the live spat under a binocular microscope revealed the loss of velum. The crawling movement was brisk unlike the gregarious movement of the aduct snails. The tentacles, as well as the foot, could be stretched substantially and the chromatophores were scattered in the foot as well as in the neck region. The head was pale.

At four-whorled stage (Figs.125.C & D), the shell became much thicker. Oral aperture was flared. The periostracum was brownish. The upper two rows of axial ribs were dark while the bottom was pale yellow. The foot and tentacles were strongly coloured with black chromotophores. The spat measured about 0.7 mm.

Further development led to calcification of shell with uniform brownish black appearance. The axial ribs and spirals were gradually developed and strongly sculptured. Comparatively broader body whorl got narrower with growth and at 7 and 8 whorled stage, the shell became uniformly turrated similar to that of adult and measured about 1.0 mm and 1.7 mm respectively (Figs.125.E & F).

6.4 DISCUSSION

The male reproductive system in C. (C.) cingulata is characterised by (1)the absence of a seminal vesicle, (2)the presence of prostate gland, (3)the genital groove divided into 2 lamellae, (4)occurrence of eupyrene and apyrene sperms and (5)absence of a copulatory organ. In all these characters, C. (C.) cingulata resembles closely T. telescopium, described by Swaminathan (1961). However, the description of C. californica by Bright (1960) differs, in that, it has a penis for sperm transfer. Woodard (1934), Johansson (1947,'53), Fretter (1951), Fretter and Graham (1962), Dazo (1965), Houbrick (1971,'73), Cannon (1975) and

Fretter (1984) who studied the reproductive system of Cerithiacea, did not report any copulatory organ. In the case of C. (C.) cingulata also no penis was observed.

Production of eupyrene and apyrene sperms is known in cerithiaceans (Fretter, 1951; Swaminathan, 1961; Fretter and Graham, 1962; Dazo, 1965; Houbrick, 1973; Cannon, 1975; Manmadha Rao, 1977). Reinke (1914) suggested that apyrene sperms may serve as nurse cells to the eupyrene sperms after copulation and before the latter reached the receptaculum seminis. In addition, they may release some substance on disintegration, which may induce eupyrene sperms as well as the eggs for fertilization. Formation of spermatophore was attributed to apyrene sperms by Woodard (1934, '40) in the case of Goniobasis, which was confirmed by Dazo (1965). According to the former, the spermatophore or the clump of spermatozoa, was formed by the entanglement of flagella of apyrene sperms, while the eupyrene sperms were inactive and passively included. Since the eupyrene spermatozoa do not clump in the absence of apyrene sperms, the phenomenon of clumping may be a mechanism which ensures the seggregation and final disposition of the eupyrene sperm in the female duct. It also prevents the premature dispersal of eupyrene sperms prior to fertilization.

The eupyrene and apyrene sperms agree with the description of Fretter (1951) working on Cerithiopsis, of Woodard (1934, '40) and Dazo (1965) on Goniobasis, of Swaminathan (1961) on T. telescopium, of Houbrick (1973) on Cerithium and of Franzen (1956) on Bittium and Scala.

Formation of spermatophore was to ensure the transfer of sperms into the female duct in the absence of a proper copulatory organ for sperm transfer and was reported in Littorina (Lenderking, 1954), in vermitids (Hadfield, 1969), in Diodora (Medem, 1945), in neritids (Bourne, 1908; Govindan, 1974), in Cerithium (Houbrick, 1973) and in Goniobasis (Jewell, 1931; Woodard, 1934, '40; Dazo, 1965). Houbrick (1973) reported the loss of spermatophores during pairing in a related species Cerithium muscarum. Similar incidance was observed in the case of C. (C.) obtusa, also during the coarse of present observation, but not in C. (C.) cingulata.

The female reproductive system of C. (C.) cingulata shows similarity with that of T. telescopium (Swaminathan, 1961) and also with those of related Cerithiids (Johansson, 1947, '56; Fretter and Graham, 1962; Houbrick, 1973, '74a, '78) and pleurocerids (Dazo, 1965). Unpaired ovary, simple oviduct, distal seminal receptacle, sperm collecting gutter

with a ciliated tube leading to the sperm collecting pouch, ciliated site of fertilization in the oviductcal groove, glandular portion of medial lamellae producing albuminous fluid distally and secreting jelly-like capsule proximally, were all described by the above workers. The occurrence of such a system in these forms in spite of their different habits of life may be due to their common ancestry (Houbrick, 1973).

Both the gonads and gonoducts resemble each other in basic cell structure. However, they differ in the gonadial product, the eupyrene and apyrene sperm in the testis and ova in the ovary. The colour differentiation appears to be due to the follicular reserves. The closed gonoducts are similar, with simple histological structures. In the case of the open pallial gonoduct, it was much simple in the case of male, but complex in the case of female. Eventhough they are basically similar in both the sexes, the cellular modification (ciliated and glandular) is more in the female, to suit the collection and retention of sperms, fertilization and egg laying. Thus, when compared to simpler prostate in the male, the female has a glandular region in median lamina (albumen and capsular), and a ciliated tube for transportation of sperms from the sperm

collecting gutter to the sperm collecting pouch, all of which differ from that of the male. Similar observations have already been made by Fretter (1951), Houbrick (1973, '78) and Cannon (1975) in related species.

Periodicity in spawning among marine invertebrates was reviewed by Giese (1959) and even tropical marine invertebrates appear to breed during certain periods of the year (Gunter, 1957; Vohra, 1970; Houbrick, 1973; Balaparameswara Rao, 1975a; Manmadha Rao, 1977). C. (C.) cingulata was observed to breed in the Adyar estuary during January-June and in Kundugal point during January-May (Sadasivan, 1947). Natarajan (1958) observed the egg mass of the same species from January to September with negligible quantity in October-December at Mandapam area. In the present observation also, ripe individuals occurred all through the year, but in greater percentage during January-September period. Abundance of egg mass and dominance of veligers in the plankton also indicate a well marked seasonality in spawning. Panikkar and Aiyer (1939) observed individuals of C. (C.) cingulata with ripe gonads during all months, but reported that active breeding did not take place all the year round. Houbrick (1973) and Manmadha Rao (1977) also observed definite breeding seasons for Cerithium and Clypeomorus

respectively, though mature specimens were found throughout the year. In the case of C. (C.) cingulata, the breeding activity extends from January to October (except monsoon season) and active spawning was however restricted to four months (February-May).

Both exogenous and endogenous factors tend to control the breeding activity of prosobranchs (Fretter, 1984). Among the exogenous factors, temperature and light are regarded as most important in temperate waters (Fretter, 1984). However, Giese (1959) regarded temperature alone was not a spawning stimulus. Webber and Giese (1969) stated that nutrition did not appear to control gametogenesis. Feare (1970) concluded that growth and gonadal development depended on rates of assimilation of food and of metabolic processes within the body; unless food intake and assimilation was increased substantially, both reproductive and growth activities would suffer. Lunar cycle (Fox, 1932; Brewin, 1942), rough weather (Heath, 1905), rainfall (Baker, 1968), wave action (Young, 1946), rough water (Grange, 1976) and mechanical shock (Field, 1922; Orton, 1924) were all found to induce spawning activities to some extent.

Harmones released into the surrounding water by mature animals appear to act as stimuli, resulting in mass

spawning (Clark, 1965). Tombes (1970) suggested that sexual maturation of prosobranchs may be related to certain groups of neurosecretory cells, while Linkey (1933) observed the occurrence of a genital hormone controlling reproduction in animals.

Effects of salinity on reproduction of estuarine animals are reported in the works of Butler (1949) on Ostrea virginica, who stated that gametogenesis was inhibited in low saline conditions. Similarly in India, Rao (1951, '56) observed that an optimum salinity is required for the breeding activities of Crassostrea madrasensis

Vohra (1970) stated that the spawning period of C. (C.) cingulata, coincided with the change of north-east and south-west monsoon months in Singapore when the precipitation was lower and salinity somewhat higher. He also concluded, based on the earlier works, that many tropical animals exhibit seasonal reproductive activity, contrary to the generally held opinion, that since there were no well-marked climatic seasons, there is no biological seasonality. Houbrick (1973) suggested the temperature and photoperiod to be remote causes for the initiation of gametogenesis in Cerithium, and once the process is initiated, further changes in temperature and photoperiod do not affect the

spawning activity. In the present study, gametogenesis appeared to take place throughout the year but spawning activity showed seasonality in that there was no spawning during the cooler northeast monsoon months of October - December when salinity also tended to be very low. It may be of significance to note that when the occurrence of egg masses was noted as early as in January in 1983, it was found only in large numbers from April in 1984. There was no substantial lowering of salinity in the former year when compared to the latter. It may also be of interest to note that growth was not disturbed throughout the period of observation i.e. from September 1982 to August 1984 (vide Chapter 4). Therefore, optimal conditions for growth and breeding activities appear to be varied .

C. (C.) cingulata matures in the second year of life and spawns at the same age. Manmadha Rao (1977) observed 12 mm as the size of maturity for Clypeomorus and attainment of maturity at a very small size appears to be not uncommon, among these snails.

Condition factor (Kn Index) is another aspect of biology least studied among prosobranchs. The consistantly high values around 1 are points of ponderance. These high values in C. (C.) cingulata indicate continued good condition

correlated to continuous spawning as in the case of fishes (Le Cren, 1951).

In C. (C.) cingulata, sex reversal was not evident Only in large size groups females outnumbered males. This may be due to differential mortality among sexes, as explained by Feare (1970) in the case of Nucella.

Pairing and courtship among Prosobranchs were reviewed by Fretter (1984), who stated that successful spawning depended upon recognition of opposite sex and mutual stimulation by partners, to induce simultaneous shedding of gametes. Aggregation of adult individuals of C. (C.) cingulata upshore was observed by Vohra (1970). Sex recognition may be related to secretion of pheromones (Fretter, 1984). In the aphallic Cerithium, the male attaches to the left anterior side of the female's shell, to release a spermatophore near the inhalent siphon of female (Houbrick, 1973). Similar is the case in C. (C.) cingulata. The pairing period lasts for about one to two hours which is also similar to the findings on Cerithium (Houbrick, 1973).

Fixing the eggs to a firm substratum is common among prosobranchs (Fretter, 1984) and similar is the case with C. (C.) cingulata. Extensive literature is available

on egg masses of prosobranchs (Natarajan, 1958; Marcus and Marcus, 1964; D'Asaro, 1970; Houbrick, 1973, '78; Cannon, 1975; Manmadha Rao, 1977). The egg masses of the potamidids are given in the accounts of Habe (1965) and Ramamoorthi and Natarajan (1973). The egg mass of C. (C.) cingulata, was described by Panikkar and Aiyer (1939) and Natarajan (1958). The latter author illustrated the egg mass spawned in the laboratory as well as in the field. Fecundity and size of the eggs observed by them and in the present case are similar.

Secretions of mucus, covering the egg may be for protection against infection and to avoid desiccation (Fretter and Graham, 1964). However in the case of Nassarius obsoletus, Pechenick (1978) found that egg capsules were not hard enough to cope with continuous exposure to air.

C. (C.) cingulata spawns in the intertidal region and are often found exposed to air. Mucus covering of the eggs may offer some protection against such adverse conditions at least for few hours, until the return of next high tide.

Provision of albumen in the egg capsule for nourishing the zygote is a well established phenomenon (Fretter and Graham, 1962). The movement of embryo in the albumen mixes the enzymes released by the embryo into the surrounding

albumen, so that it becomes less viscous and is conveyed by cilia to the mouth. No nurse eggs could be recorded in C. (C.) cingulata.

Duration of larval development depends on food resources and on temperature, and varies from a few days to weeks among prosobranchs (Fretter, 1984). Natarajan (1958) recorded an incubation period of four days (before hatching) for C. (C.) cingulata in Mandapam area, while the veliger was released in 48 hours at Porto Novo area. Differences in size and shape of egg capsules and duration of larval development and metamorphosis, in different populations of the same species, have been earlier recorded in Cerithium by Houbrick (1973) and in Clypeomorus by Manmadha Rao (1977).

Early development follows a similar pattern in molluscs as given by Verdank and van den Biggelaar (1983), which involves formation of polar lobe and merging with blastomere. The significance of polar lobe formation has been discussed in detail by Verdank and Cather (1983)as it can influence morphogenesis. Blastulation and gastrulation were typical of mesogastropods described by Fretter and Graham (1962), but there were no larval kidneys as observed by Houbrick (1973) in the case of Cerithium.

Larval organs of C. (C.) cingulata, include

bilobed velum which is thickly ciliated, massive foot, operculum, tentacles, eyes, heavily yolked digestive gland, thin tube of alimentary tract and a heart which pulsates actively. These are common features among prosobranch veligers (Fretter and Graham, 1962).

Natural surface markings or sculptures of the embryonic shell are of conchological significance (Solem, 1970; Fretter and Filkington, 1971; Robertson, 1971). The protoconch in C. (C.) cingulata is pitted minutely and the body whorl striated. Similar shell sculpture was observed by Thiriot-Quievruex (1980) in Cerithium and Bittium and by Thiriot-Quievruex and Scheltema (1982) in Bittium sp.

The period of planktotrophic life varies among prosobranchs considerably from 3 to 196 days depending on temperature (Fretter, 1984). The larval phase of life history ensures maximum dispersal (Crisp, 1974) and also results in the maintanence of wide genetic variability within the species population (Scheltema, 1971; Underwood, 1974). Settlement is subjected to availability of suitable substratum and is influenced by tides, currents and other physical factors. Chemical and tactile stimuli help in the selection of proper substratum, for larval settlement as also for future life cycle (Keiselva, 1967; Struhsaker and Costlow, 1968).

Metamorphosis involves anchoring of body by secretion of mucus from the foot, loss of velum and change from planktonic microphytes to detrital food. The actual process of loss of velum was not observed which may be either by casting off or by partly absorbing or by swallowing and digesting (Fretter, 1984).

The duration of planktotrophic life of the pelagic larvae was 15 days, by which time the larvae reach 0.3 mm shell length and settle down. As per studies on age and growth, the shell length of 2 mm is attained in one month. Such growth is not impossible since the larvae settle in favourable sites with abundant food supply. Spats are very active at this stage and good nourishment so obtained may help the spat to grow fast. It may be of interest to point out that highest larval concentration in plankton was observed in April 1984 at site II. Juveniles of 2 mm were collected in the same month, which indicates the fast rate of growth in settled spat.

The results of the present study can be summarised as follows:

1. Reproductive system is simple with unpaired gonads, closed gonoducts and open pallial duct.

2. Male reproductive system comprises of testis,

vas deferens, pallial gonoduct with two laminae which are fused to the mantle. The posterior part of median lamina is glandular and acts as prostate.

3. The testis is follicular, composed of primordial tissue, spermatocytes and spermatozoa. Vas deferens possesses ciliated cells. Prostate is glandular. Seminal groove is ciliated.

4. Two types of sperms, eupyrene and apyrene could be found.

5. Female reproductive system is constituted by unpaired ovary, oviduct, and pallial oviduct comprising sperm pouch, ciliated tube, seminal receptacle, albumen and capsular glands, oviduccal groove and sperm collecting gutter.

6. The ovary is follicular comprising of oocytes and ova. Oviduct is ciliated. Ciliated tube, sperm pouch, sperm collecting gutter and oviduccal groove are ciliated, while the median lamina possesses glandular cells in albumen and capsular gland regions.

7. Both the sexes can be conveniently classified into maturing, mature and spent individuals, based on the colour of the gonad and on the stages of the development of gametes. Individuals at all stages of maturity could be

found throughout the year but from January to September, intense breeding activity, was observed.

8. The males and females of C. (C.) cingulata attain first maturity at the size of 16 mm shell length.

9. Condition factor (Kn Index) was always high and around 1 which was also indicative of prolonged breeding activity in this snail.

10. Sex was evenly distributed in the population during different months as well as in different length groups.

11. Pairing takes place during day and night times.

12. Oviposition takes place during all times of the day.

13. Egg masses are tube-like and the maximum size recorded was 232 mm.

14. Maximum fecundity recorded was 17,456.

15. Maximum number of egg mass/m^2 was in April 1984.

16. Egg is covered by a tough hyaline capsule and measures about 160 μ. The zygote is about 115 μ and is surrounded by albumen.

17. Cleavage commences with the formation of polar lobe.

18. Cleavage is unequal and spiral.

19. Sterroblastula precedes gastrulation which is by epiboly.

20. Trochophore is oval and ciliated throughout.

21. Veliger is formed in 36 hours and hatches out 48 hours after spawning.

22. Veliger possesses bilobed and ciliated velum, a pair of tentacles and eyes at the base of tentacles, extendable foot and thin operculum. Protoconch is minutely pitted but the body whorl is striated.

23. Plankton phase extends for 15 days, but the larvae attain the "swim-crawl" stage within 10 days.

24. Freshly settled spat is 2½ whorled, measures 0.3 mm and grows to 2 mm within 15 days.

Table 23. Monthwise distribution (in percentage) of maturity stages of males of C. (C.) cingulata.

Month	n	Maturing	Mature	Spent
September 1982	21	--	100.0	--
October	28	--	85.7	14.3
November	25	20.0	44.0	36.0
December	19	42.1	57.9	--
January 1983	39	20.5	79.5	--
February	28	32.1	67.9	--
March	31	22.6	74.2	3.2
April	34	14.7	85.3	--
May	42	21.4	78.6	--
June	23	8.7	91.3	--
July	40	10.0	65.0	25.0
August	32	6.4	65.6	28.0
September	29	3.4	72.4	24.2
October	16	6.3	69.7	24.0
November	29	13.8	48.4	37.8
December	29	13.8	51.7	34.5
January 1984	27	14.8	85.2	--
February	31	--	100.0	--
March	34	2.9	85.3	11.8
April	34	--	97.1	2.9
May	26	11.5	88.5	--
June	34	8.8	88.2	3.0
July	34	5.9	70.6	23.5
August	41	19.5	73.2	7.3

n = number of specimens examined.

Table 24. Monthwise distribution (in percentage) of maturity stages among females of C. (C.) cingulata.

Month	n	Maturing	Mature	Spent
September 1982	26	--	100.0	--
October	28	10.4	89.6	--
November	27	3.7	63.0	33.3
December	31	9.7	19.4	70.9
January 1983	50	44.0	56.0	--
February	41	26.3	73.7	--
March	54	16.7	75.9	7.4
April	48	25.0	75.0	--
May	51	43.1	56.9	--
June	41	9.8	56.1	34.1
July	35	8.6	77.1	14.3
August	35	5.7	71.4	22.9
September	34	--	97.0	3.0
October	25	8.0	80.0	12.0
November	30	16.7	53.3	30.0
December	41	9.8	53.7	36.5
January 1984	36	13.8	80.6	5.6
February	34	--	100.0	--
March	36	11.1	77.8	11.1
April	35	6.1	93.9	--
May	44	2.3	70.5	27.2
June	31	3.2	83.9	12.9
July	42	--	88.1	11.9
August	40	5.0	62.5	32.5

n = number of specimens examined.

able 25. Percentage composition of indeterminate, male and female in various length groups of C. (C.) cingulata.

ength (mm)	Indeter-minate	Male	Female
1	100.0	--	--
2	100.0	--	--
3	100.0	--	--
4	100.0	--	--
5	100.0	--	--
6	100.0	--	--
7	100.0	--	--
8	100.0	--	--
9	100.0	--	--
10	100.0	--	--
11	100.0	--	--
12	96.4	2.9	0.7
13	83.2	11.5	5.3
14	73.0	14.3	12.7
15	66.6	16.7	16.7
16	36.0	25.3	38.7
17	27.3	30.3	42.4
18	26.5	35.0	38.5
19	10.1	38.4	51.5
20	6.0	42.9	51.1
21	4.2	43.7	52.1
22	3.4	48.3	48.3
23	0.8	42.4	56.8
24	--	45.7	54.3
25	--	45.8	54.2
26	--	39.6	60.4
27	--	47.0	53.0
28	--	34.1	65.9
29	--	33.3	66.7
30	--	41.4	58.6
31	--	30.0	70.0
[illegible]	--	42.1	57.9

Table 26 Percentage composition of the two sexes of C. (C.) cingulata in different months.

Month	n	Male	Female
September 1982	47	44.7	55.3
October	56	50.0	50.0
November	52	48.1	51.9
December	50	38.0	62.0
January 1983	89	43.8	56.2
February	69	40.3	59.7
March	85	36.5	63.5
April	82	41.5	58.5
May	93	45.2	54.8
June	64	35.9	64.1
July	75	53.3	46.7
August	67	47.8	52.2
September	63	46.0	54.0
October	41	39.0	61.0
November	59	49.2	50.8
December	70	41.4	58.6
January 1984	63	42.9	57.1
February	65	47.7	52.3
March	70	48.6	51.4
April	69	49.3	50.7
May	70	37.1	62.9
June	65	52.3	47.7
July	76	44.7	55.3
August	81	50.6	49.4

n = number of specimens examined.

Table 27. Percentage composition of two sexes in C. (C.) cingulata in different length groups.

Length (mm)	n	Male	Female
12	5	80.0	20.0
13	19	68.4	31.6
14	34	52.9	47.1
15	46	50.0	50.0
16	71	39.4	60.6
17	96	41.7	58.3
18	86	47.7	52.3
19	89	42.7	57.3
20	125	45.6	54.4
21	114	45.6	54.4
22	112	50.0	50.0
23	117	42.7	57.3
24	142	45.8	54.2
25	96	54.2	45.8
26	96	39.6	60.4
27	100	53.0	47.0
28	82	34.1	65.9
29	69	33.3	66.7
30	58	41.4	58.6
31	40	30.0	70.0
32	19	22.1	57.9
33	4	75.0	25.0
34	1	--	100.0

n = number of specimens examined.

Table 28. 'Kn' Index in C. (C.) cingulata in different months.

Month	Index
September 1982	1.01
October	1.01
November	0.90
December	1.01
January 1983	1.01
February	1.02
March	1.03
April	1.02
May	1.02
June	1.03
July	1.02
August	1.02
September	1.03
October	1.03
November	1.02
December	1.01
January 1984	1.02
February	1.02
March	1.03
April	1.02
May	1.02
June	1.02
July	1.00
August	1.01
September	1.00

Table 29. Percentage of worm infested specimens of C. (C.) cingulata in different months.

Month	n	Worm infested
September 1982	117	---
October	124	6.9
November	131	--
December	141	--
January 1983	150	--
February	135	--
March	153	1.3
April	111	--
May	152	2.0
June	133	3.0
July	147	6.8
August	138	2.2
September	151	6.6
October	85	11.8
November	121	0.8
December	130	7.7
January 1984	123	4.1
February	114	3.5
March	107	6.5
April	110	9.1
May	119	6.7
June	118	0.8
July	126	--
August	91	--

n = number of specimens examined.

Table 30. Egg mass and veliger larvae of S. (C.) cingulata recorded in Vellar estuary in different months

Month	Number of egg mass/m^2	Number of veliger/m^3
September 1982	13	1470
October	1	69
November	--	--
December	--	--
January 1983	11	1225
February	10	2902
March	16	3570
April	13	1100
May	14	1643
June	12	1495
July	13	2894
August	12	1495
September	3	3709
October	--	--
November	--	--
December	--	--
January 1984	12	2792
February	10	5417
March	5	503
April	20	17534
May	12	1516
June	12	1350
July	13	1524
August	12	1665

LIST OF ABBREVIATIONS USED IN FIGURES

ac	:	acrosome
alf	:	albuminous fluid
alg	:	albumen gland
apci	:	apical cilia
apw	:	apical whorl
arc	:	archenteron
asp	:	anterior siphonal canal
axr	:	axial rib
bc	:	beak
bw	:	body whorl
cg	:	capsule gland
chr	:	chromosomes
chr.dip.		chromosomes in diplotene stage
ci	:	cilia
cl	:	columella
con	:	connective tissue
cw	:	capsular wall
dg	:	digestive gland
dt	:	digestive tubule
e	:	eye
egm	:	egg mass
f	:	foot
fo	:	follicle
gf	:	genital fold
ll	:	lateral lamina
mac	:	macromeres
mic	:	micromeres
ml	:	median lamina
mt	:	metatroch
mu	:	mucus covering
n	:	nucleus
nl	:	nucleolus

oa	:	oral aperture
od		oviduct
odg	:	oviduccal groove
ol		outer lip
ooc	:	oocyte
op	:	operculum
ov	:	ovary
pb	:	polar body
pl	:	polar lobe
pod		pallial oviduct
pooc	:	primary oocyte
pro	:	protoconch
prs	:	prostate gland
pspcy		primary spermatocyte
rcs	:	seminal receptacle
seg	:	seminal groove
sh	:	shell
secooc	:	secondary oocyte
sp	:	sperm
spcy	:	spermatocyte
spg	:	sperm collecting gutter
spgl	:	spiral groove
spr	:	spiral rib
spt	:	spermatid
st	:	statocyst
str	:	striations
t		testis
te	:	tentacle
vd	:	vas deferens
ve	:	velum
visc	:	visceral organs
yg	:	velum
z	:	zygote

Fig. 108. C. (C.) cingulata

A) Male reproductive system

B) Female reproductive system

C) Eupyrene sperm

D) Apyrene sperm

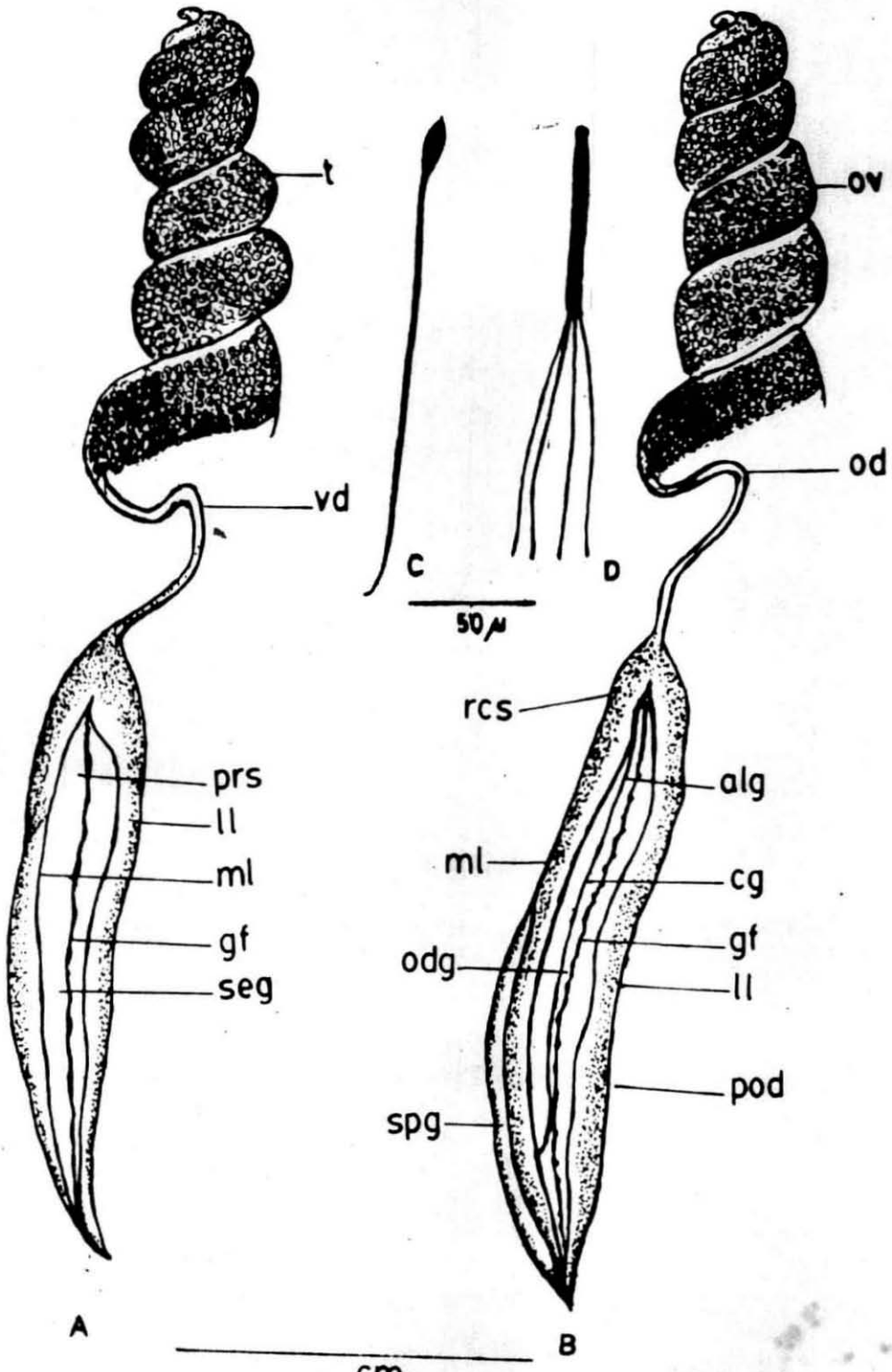
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FIG 108

Fig. 109. Follicles of testis Zenker - Heidenhain's iron haemotoxylin - 5μ. x75

Fig. 110. Closer view of a testicular follicle, showing sperms in maturing stages. Zenker - Heidenhein's iron haemotoxyline - 5μ. x300

Fig. 111. Spermateleosis (enlarged view of the above). Zenker - Heidenhain's iron haemotoxylin - 5μ. x750

Fig. 112. Meiosis in primary spermatocytes (diakinetic stage) and spermateleosis. Zenker - Heidenhain's iron haemotoxylin - 5μ. x750

Fig. 113. Meiotic divisions - stages in the primary spermatocytes. Zenker - Heidenhain's iron haemotoxylin - 5μ. x750

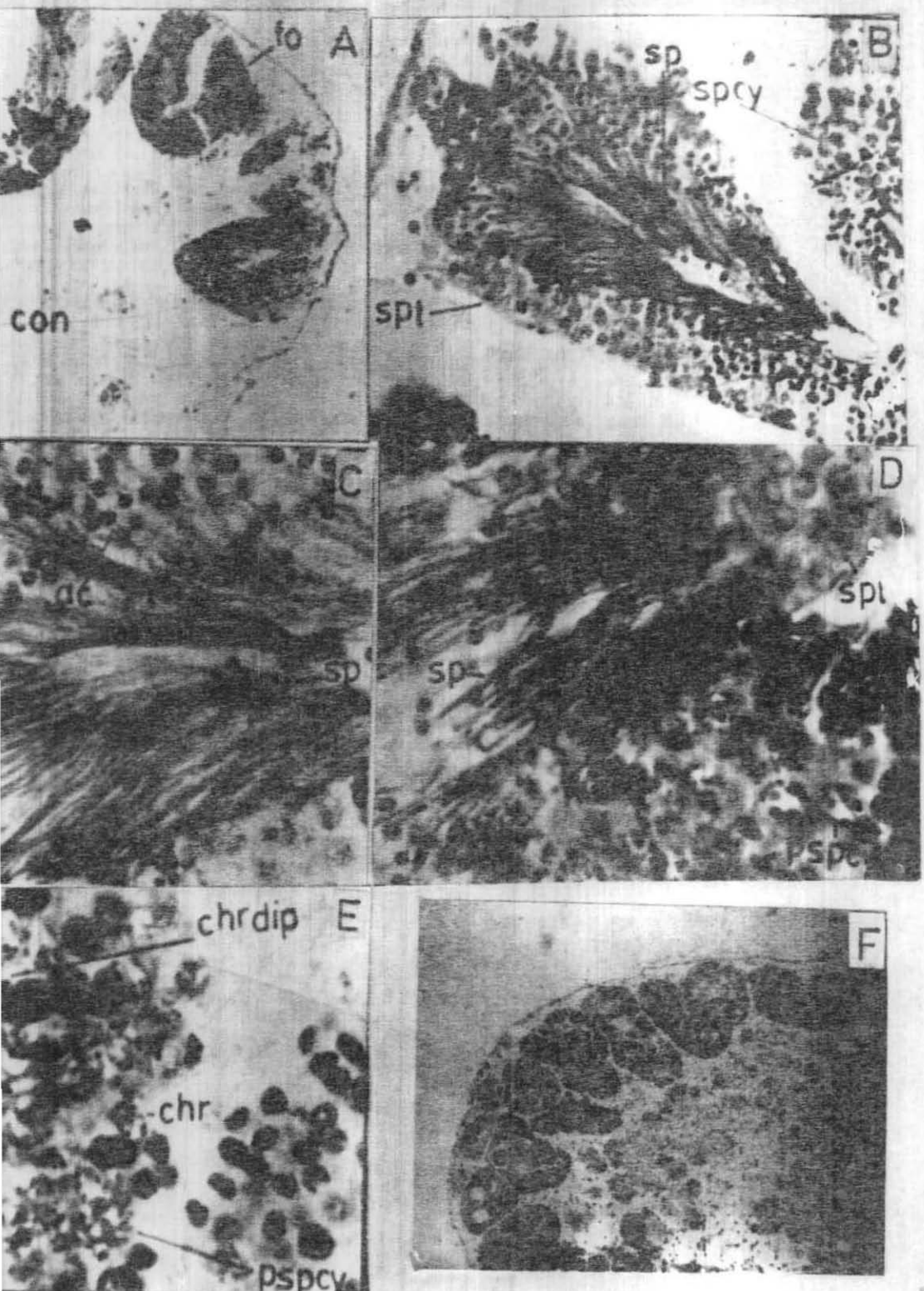
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Fig. 114. Ovarian follicles. Zenker - Heidenhain's iron haemotoxylin - 5μ. x75

Fig. 115. Another view of ovarian follicles. Zenker - Weigert's iron haemotoxylin - Biebrich scarlet - 5μ. x150

Fig. 116. Enlarged view of the above - the primary oocytes showing meiotic stages. Zenker - Heidenhain's iron haemotoxylin - 5μ. x300.

Fig. 117. A single oocyte in late diplotene stage. Zenker - Heidenhain's iron haemotoxylin - 5μ. x750

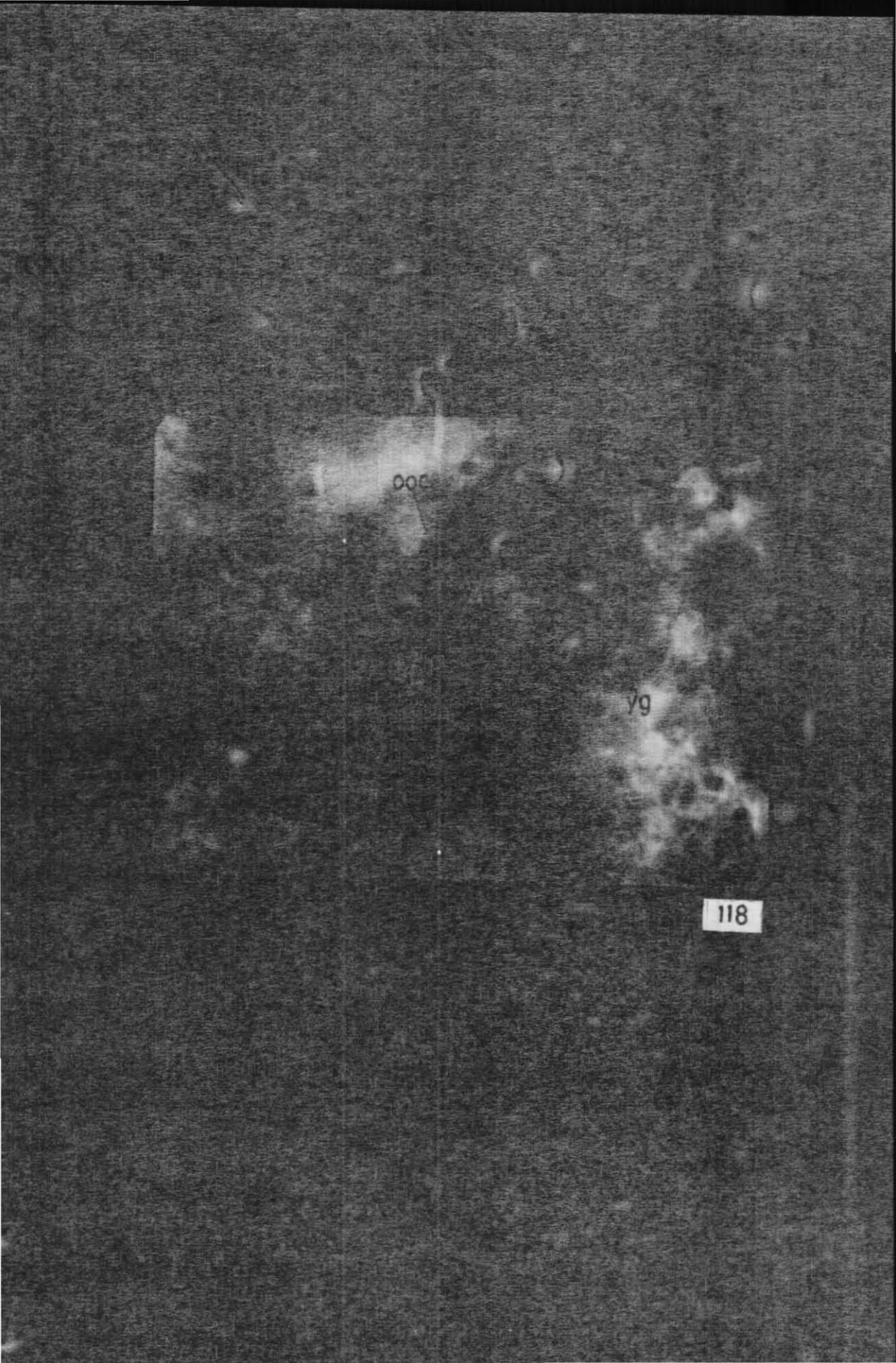
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Fig. 119. Mating specimens of C. (C.) cingulata.

Fig. 120. Spawning in C. (C.) cingulata - egg mass in the furrow.

Fig. 121. 23 cm long egg mass of C. (C.) cingulata - egg mass removed from substratum and kept on a tray with a scale.

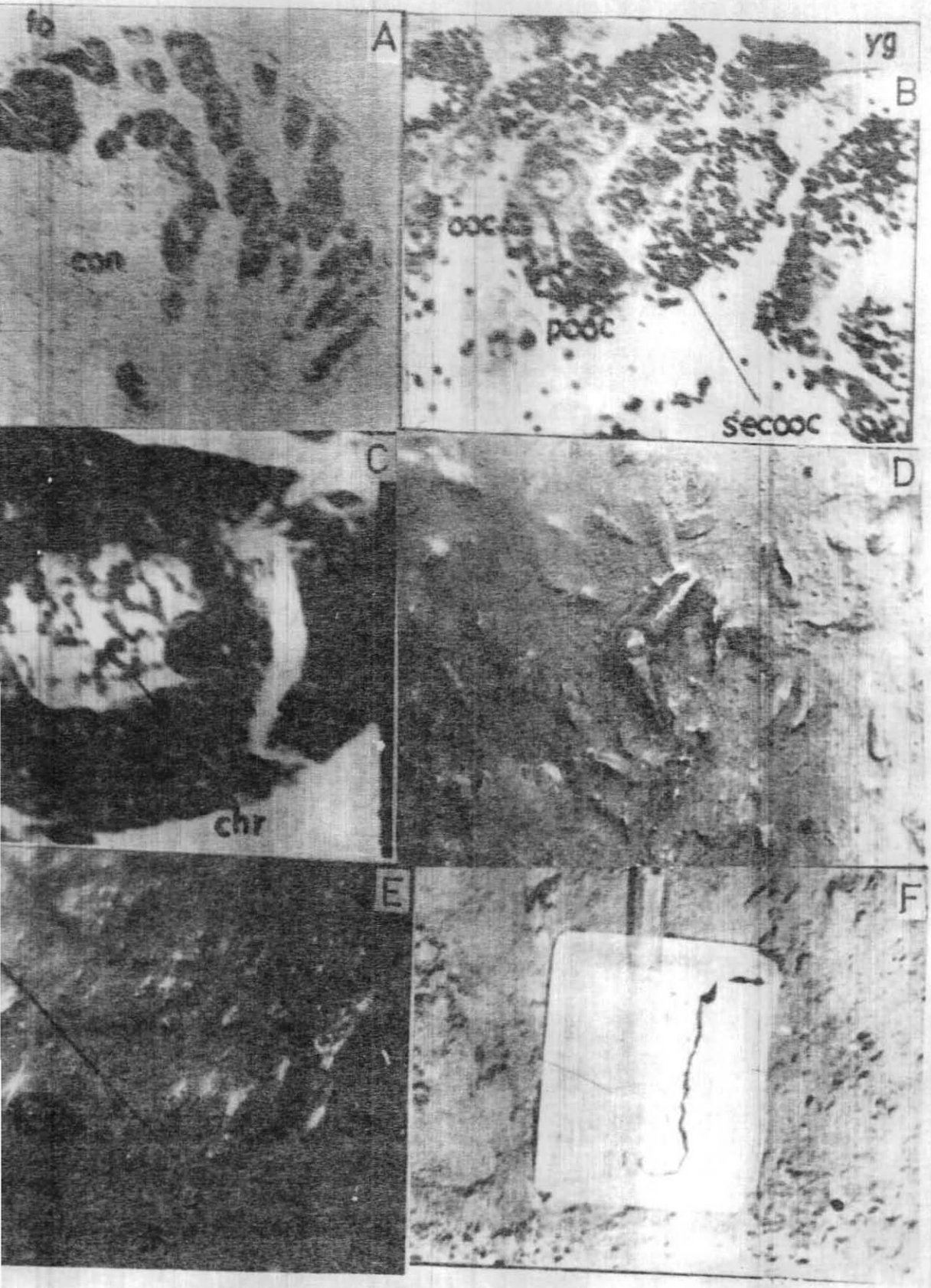
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Fig. 122. Development of C. (C.) cingulata

A and B) Enlarged portion of an egg mass

C) A single egg

D) Formation of polar lobe

E) Withdrawal of polar lobe and formation of polar body

F and G) First cleavage

H) 2-celled stage

I) 4-celled stage

J) 8-celled stage

K) Sterroblastula

L) Gastrulation

M) Gastrula

N) Early trochophore

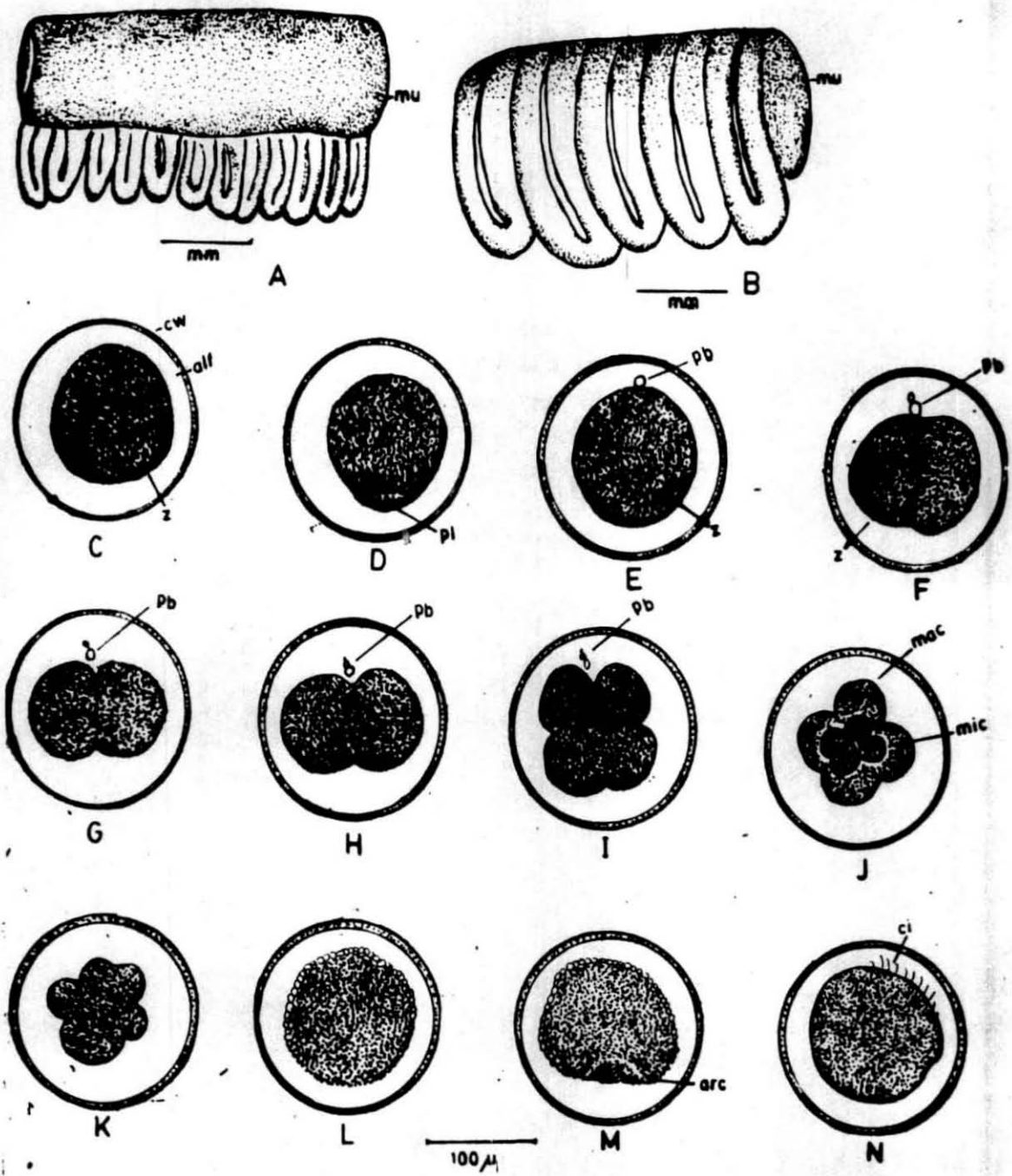
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FIG 122

Fig. 123. Development of C. (C.) cingulata (contd.)

A) Trochophore
B, C and D) Formation of velum
E and F) Early veliger stage
G) Late veliger stage
H) Veliger prior to hatching
I) Free veliger
J) Shell of the above
K) One day old veliger
L) 2 days old veliger
M) 4 days old veliger
N) 5 days old veliger
O) 7 days old veliger
P) 9 days old veliger

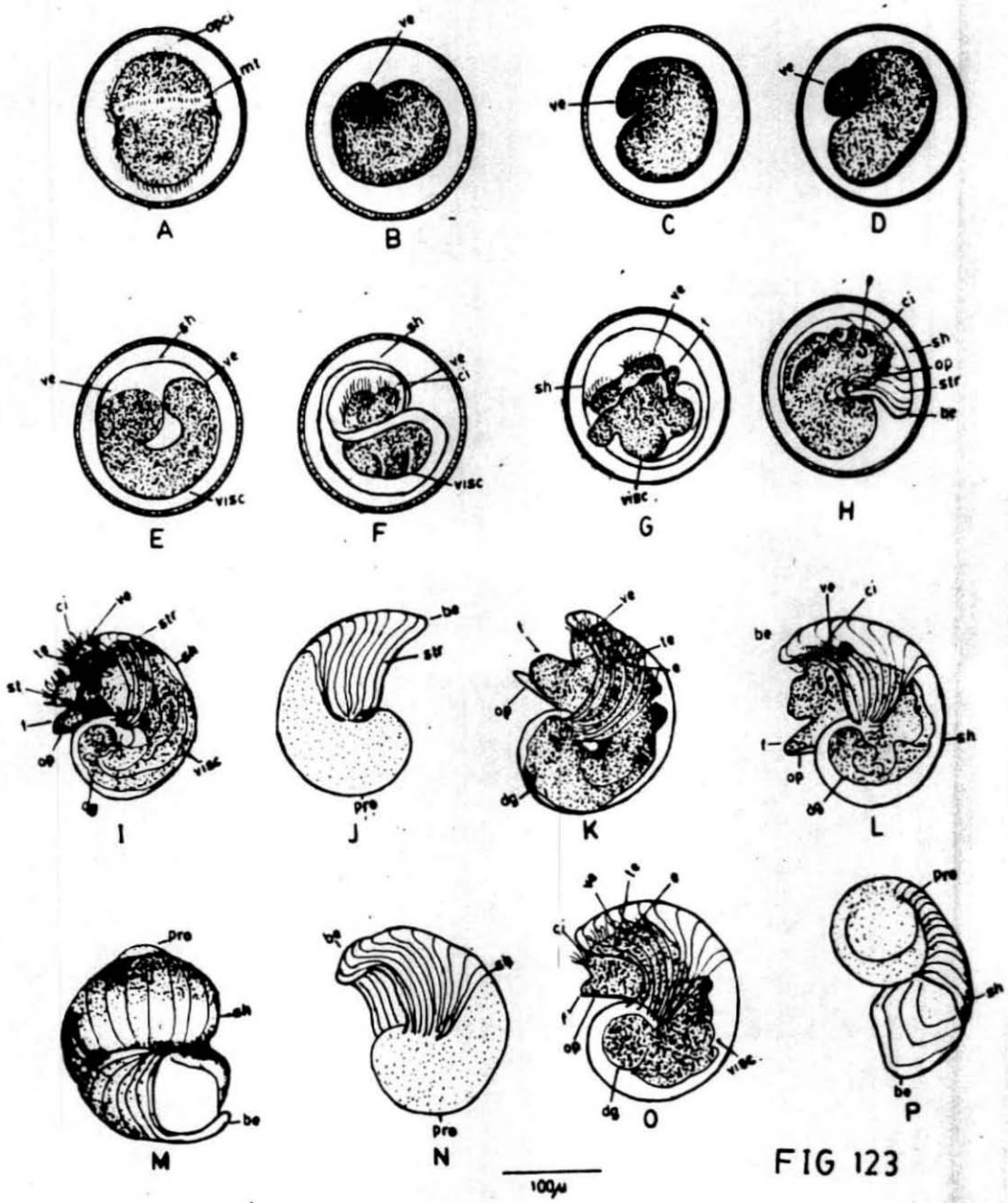
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FIG 123

Fig. 124. Development of C. (C.) cingulata (contd.)

A) 9 days old veliger
B) 10 days old veliger
C) 12 days old veliger
D and E) 13 days old veliger
F) 15 days old veliger

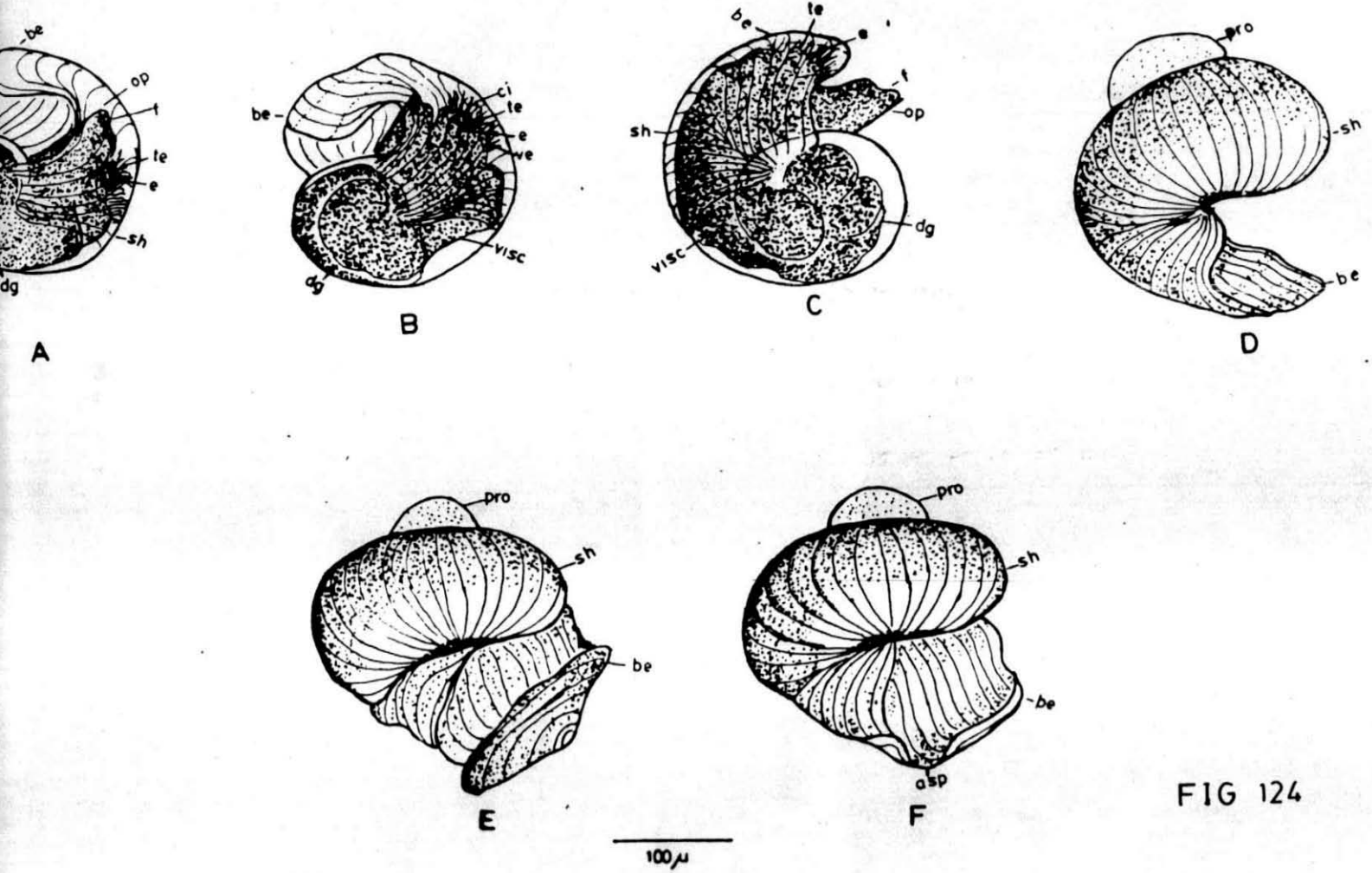
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FIG 124

Fig. 125. Development of C. (C.) cingulata (contd.)

A - F). Spats

A and B) Apertural and abapertural views of 0.3 mm spat

C and D) Apertural and abapertural views of 0.7 mm spat (4-whorled)

E) Abapertural view of 1.0 mm spat (7-whorled)

F) Apertural view of 1.7 mm spat (8-whorled)

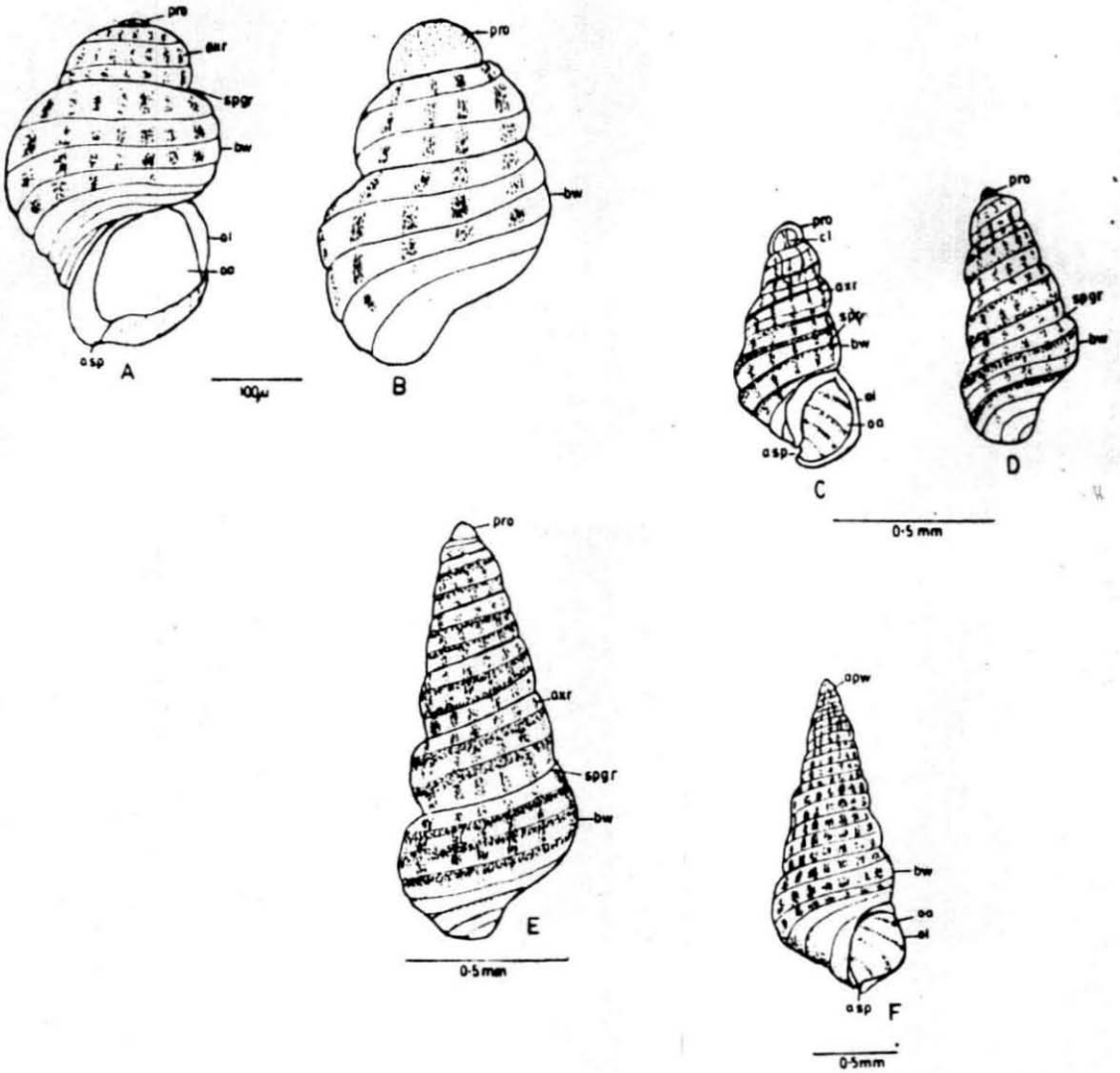
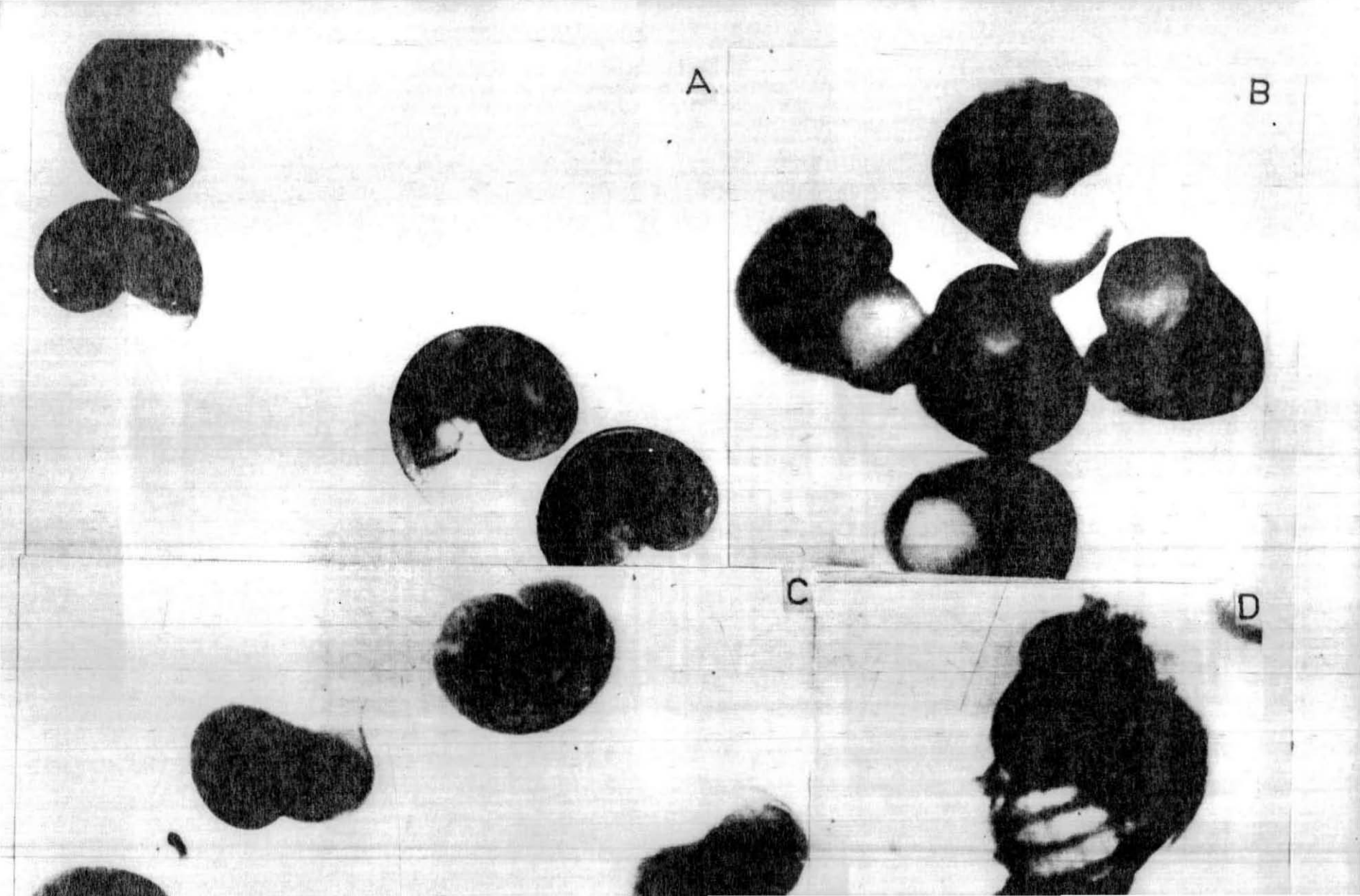


FIG 125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GENERAL REMARKS

Snails of the family Potamididae (Super family Cerithiacea, Order Mesogastropoda, Subclass Prosobranchia) are represented by three species at Porto Novo viz., Cerithidea (Cerithideopsilla) cingulata, Cerithidea (Cerithidea) obtusa and Telescopium telescopium. C. (C.) cingulata occurs abundantly in the intertidal region of the estuary. C. (C.) obtusa is endemic to the mangrove forests of Pichavaram in Killai lagoon while T. telescopium is present in both the areas.

The Vellar estuary is connected to the Coleroon estuary by channels and lagoons, running parallel to the sea. Within this lie, a net work of small islets with mangrove vegetation, known as Pichavaram mangroves. This estuarine and backwater complex offers ideal environmental conditions for the potamidid snails, amply evidenced by the dominance of this group, over others, in general.

The three species resemble each other in gross anatomical features of alimentary, reproductive and other systems, but differ in shell size, shape and sculpture. In C. (C.) cingulata, axial ribs and spiral ridges are well developed, thus giving the appearance of nodules. In C. (C.) obtusa, the axial ribs predominate over spiral

ridges while in T. telescopium, the axial sculpture is totally absent. Decollation of the apical whorl is limited to the protoconch in C. (C.) cingulata and T. telescopium, but affects many whorls in C. (C.) obtusa. Columella is strong in the case of former two species, but weak in C. (C.) obtusa. Aperture is oval and the operculum spherical, with a central nucleus, in all species (common to Potamididae).

The alimentary system includes the buccal cavity, enclosing chitinous jaws, odontophore, radula, radular sac, much reduced salivary glands, the oesophagus, a large stomach and style sac containing an elongated and narrow crystalline style, digestive gland, intestine and the rectum. The reproductive system includes the gonad, gonoduct and an open pallial duct. No copulatory organ is present. Two types of sperms, eupyrene and apyrene, are met with. A spermatophore is present. The kidney is the excretory organ with a prominent opening. The circulatory system includes a two chambered heart and pallial sinuses, which are poorly defined. The nervous system includes a nerve ring around oesophagus and fine nerves running from the ganglia to various organs. Sense organs are a pair of eyes, osphradium and a statocyst.

C. (C.) cingulata is dominant below MWL while

T. telescopium is found above MWL wherever the two species occur together. In the mangrove, C. (C.) obtusa is found near the fringe and also on the branches of Rhizophora, but T. telescopium is restricted to the ground at the HWL. These species utilise similar food spectra, i.e. fine detritus in the mud rich in organic matter.

Electrophoretic studies also reveal the distinction between these three species and genera. C. (C.) cingulata and C. (C.) obtusa differ from each other in 25% or less number of fractions, while both of them differ from T. telescopium in 25 to 54% of the number of fractions. The shell and radular characters, as also the preference to exposure, rather than to submersion of C. (C.) obtusa makes it distinct from other two potamidids. Among the three potamidids, the smallest species, C. (C.) cingulata has the largest biomass of 12,500 snails/m^2.

The Vellar estuary has a perennial opening to the Bay of Bengal and so semidiurnal tides bring neritic waters into the estuary. This estuary is notably influenced by rainfall during north-east monsoon (October-December). The temperature varied from 24° to 32°C in surface waters and salinity from near freshwater to 35.75‰, depending upon fluviatile inflow and penetration of neritic waters.

Salinity was maximum during summer (April-June) and pre-monsoon (July-September) and low during monsoon (October-December). Dissolved oxygen content of the estuarine water ranged from 3.19 to 6.49 ml/l and was high during monsoon and postmonsoon (January-March) periods. The pH of both water and sediment was alkaline and the organic carbon content varied from 3.1 to 17.3 mg/g, with generally high values in summer. The texture of the substratum was mainly clayey sand. Phytoplankton showed a peak during late summer, followed by that of zooplankton during early premonsoon. Macrovegetation composed mainly of angiosperms and green algae. Mats of Enteromorpha were abundant in the estuary.

C. (C.) cingulata is essentially euryhaline and copes with low and high salinities in the estuary. It is active normally in water with a salinity of 25 to 35‰, but only on acclimation shows normal activity in 10 to 20‰. On the other hand, salinity below 5‰ was not tolerated and was lethal to the snail. Temperature of water beyond 42°C inhibits the activity of the snail and mortality occurs at 50°C.

Exposure of C. (C.) cingulata results in water-loss from the soft parts of the body. The water-loss was more on the first day but declined steadily during subsequent

days. The water loss, upto 13% of the total body weight, was tolerated but beyond that the mortality rate was total. Exposure for 12 days led to lethal weight loss. Closure of the operculum is a protective measure taken by the snail against changes in salinity or temperature or during desiccation.

Horizontal distribution of C. (C.) cingulata was from river mouth upto 8 km in the upper reaches and its vertical occurrence was between MWL and LWL only. Salinity appears to influence the limit of upstream distribution, while the effects of desiccation, predation and competition appear to be responsible for the absence of this snail above high tide levels. The presence of algal mats and clayey sand substrata with high organic carbon content were observed to favour aggregations of the snail. The river mouth (Site I) lodged large populations of C. (C.) cingulata than any other area.

Mean shell lengths in the population tend to be small during the period of spat settlement i.e., June-August. Large sized individuals were found only in the Killai lagoon area (Site III).

C. (C.) cingulata moves with the tide and can cover about 3 m per day. Feeding appears to be the main

urge for the movement of this snail. 75% of the population dispersed within 30 days from their original point of release.

C. (C.) cingulata grows to 13 mm by the end of first year of life, and to 22, 28 and 32 mm by the end of second, third and fourth years of life respectively. Growth is slowed down after 19 mm, when it attains maturity. The asymptotic length (L_∞) estimated was 39.99 - 42.0 mm which is closer to the field record (shell length 39.4 mm). Along with the length of the shell, other parts also grow isometrically. The relationship between total/flesh weight and shell length differs between adults and juveniles. Populations of C. (C.) cingulata at the Vellar estuary were composed of 0-, 1-, 2- and 3-year classes of which 0-year class was more abundant. The life span of the snail appears to be of four years under normal circumstances.

C. (C.) cingulata possesses a digestive system which is extremely suitable to ingest, sort, digest and to absorb detrital food. The foregut comprises the mouth, buccal cavity and oesophagus. In the buccal cavity the chitinous jaws, radula, radular sac and odontophore are lodged. Worm-like salivary glands open into the buccal cavity. Extensive musculature in this region helps in

ingestion and passing of the food into oesophagus. The oesophagus secretes copious mucus (both acidic and neutral) to bind the food material, before passing it on to the stomach, by ciliary action.

The midgut includes the stomach, the crystalline sac and style and the digestive gland. Enzymes secreted by the stomach wall, the crystalline style and the digestive gland act upon food particles in the stomach. The crystalline style rotates against a chitinous gastric shield to release the enzymes by dissolution. The digestive gland contains secretory and absorptive cells. The former cells also release the waste products in the form of spherules.

The hind gut comprises the intestine and rectum. Intestine in C. (C.) cingulata carried out both digestion and absorption. The rectum possesses mucus secreting cells and the secreted mucus binds the faecal matter which are expelled into the mantle cavity by ciliary action. An interesting feature of the alimentary system of C. (C.) cingulata is the phagocytic activity by amoebocytes in the stomach, digestive gland and intestine, where they absorb digested food particles and transport them for storage in the acini of connective tissue.

The pH in the gut varied, from neutral in the

buccal cavity to slightly acidic in oesophagus, strongly acidic in the stomach, style sac, digestive gland and intestine, but alkaline in the rectum. The neutral condition in the buccal region helps to bind the food particles by mucus. Acidic nature in other regions ensures optimum enzymatic activity and the alkaline nature in the rectum is helpful again for binding the faecal matter by mucus.

C. (C.) cingulata has strong sucroclastic enzymes and weak proteolytic and lipolytic enzymes in its digestive system. Gut of C. (C.) cingulata is inhabited by amylolytic, cellulolytic, gelatinolytic, caseinolytic and lipolytic bacteria. Their populations are more in the foregut and hindgut but least in the stomach and digestive gland. These bacteria appear to aid in preliminary digestion of food so as to be acted upon by the native enzymes for complete digestion.

C. (C.) cingulata subsists on detrial organic matter rich in vegetal matter. Most of these reserve products are rich in saccharides (both simple and complex types) and poor in protein and lipids. An elaborate system of sucroclastic enzymes is suited for the diet. The gut microflora seem to help by splitting the complex matter into simpler products, which can then be easily digested by native enzymes.

The simple reproductive organs of C. (C.) cingulata are gonad, closed gonoduct and open pallial duct. No sexual dimorphism is discernible. The male is without a copulatory organ, but the wastage of sperms are avoided by the formation of a spermatophore, which encloses both eupyrene and apyrene sperms. Transfer of spermatophore by the male, into the inhalent stream of the female during mating, ensures the safe disposition of sperms into the female.

The female gonoduct is elaborated to receive, retain and release the sperms for fertilization. There is a sperm collecting gutter which receives the spermatophore and transports eupyrene sperms through the sperm collecting pouch to the seminal receptacle. From there, during spawning, the sperms pass on to the site of fertilization. These fertilised ova first pass through the albumin gland where the albumen is secreted around zygote and then through the capsular gland, where the jelly-like capsule around the egg is formed. These eggs are laid in the form of mucus strings as long coils. Maximum fecundity of 17,456 eggs was recorded in a single egg string of 232 mm long laid by a snail of 23 mm in shell length. The spawning season is prolonged, from January to September, in the Vellar estuary. Both male and female attained maturity at the shell length

of 16 mm, when the snail is around 15 months old. The condition index was always high. Sex was evenly distributed during different months in different size groups of the population.

Cleavage commences within 30 minutes after the egg is laid. Cleavage is spiral and unequal. Trochophore is suppressed. A veliger is formed in 36 hours but hatching takes place 48 hr after spawning. Planktotrophic veligers swim actively, search and locate suitable substrata for settlement in about 15 days. These spats grow actively and become juveniles measuring about 2 mm in shell length within one month.

The foregoing account clearly indicates the successful colonisation and dominance of C. (C.) cingulata in the Vellar estuarine environment. Its success is due to the facts that (1) it grows actively; (2) it utilises the maximum nourishment from the detrital food, (3)it attains maturity early, (4)its fecundity is high and its breeding season is well extended for nine months in a year, and (5)it is typically euryhaline capable of adjusting to low and high salinties. Because of its very high biomass, active growth, early maturity, high fecundity and hardy nature, C. (C.) cingulata can be considered as a very good food resource

for commercial fish culture. Its utilisation in the manufacture of special lime is already in vogue (Hornell, 1951). Except for this conventional use, non-conventional utilisation of this resource for preparation of poultry feed and fish feed, may be most viable and cheap. A study in this direction is imperative as a follow up of the present investigation so as to utilise the abundant C. (C.) cingulata as a cheap feed resource for other culturable finfish and shellfish.

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1. Distribution of seed clams of Meretrix casta (Chemnitz) in Vellar estuary. Proc. Symp. on Coastal Aquaculture, 2: 561-563 (1983).

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C. General:

18. A large scale washing ashore of marine fauna at Kovalam, south west coast of India. Indian J. Fish., 24 (1 & 2): 198-200 (1977) (with another author).

19. On a copepod parasite Pennella diodentis (Oken) with epizoic Cirreped Conchoderma virgatum (Spengler) on a new host Zanclus canescens (Linnaeus). Indian J. Fish., 24 (1 & 2): 204-206 (1977) (with another author).